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Critical Review of Estimating Benefits of Air and Water Pollution Control

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CRITICAL REVIEW OF ESTIMATING BENEFITS OF AIR AND WATER POLLUTION CONTROL

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PREFACE

This report is submitted in fulfillment of U.S. EPA contract #68-01-2821. It contains a critical review of current methods and data employed in estimating benefits of air and water pollution control.

In order to provide a balanced perspective in assessing the state-of-the-art in the "benefits area", the material in this report is derived from three types of sources:

- Extensive experience by three distinguished consultants in conceptualizing and analyzing benefit estimates;
- Recent experience in preparation of national benefit estimates by the Enviro Control staff; and
- A two-day conference on benefit estimation involving some 25 participants from a number of government, academic and private research institutions.

The three consultants on general benefit estimation, air pollution control, and water pollution control benefits were, respectively:

- Dr. A Myrick Freeman III
  Dept. of Economics, Bowdoin College
- Dr. Thomas D. Crocker
  Dept. of Economics, University of Wyoming
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  Oregon State University

The Enviro Control contributions, including preparation of the overview, as well as coordination and editing of the three papers, were made by Dr. Alex Hershaft, Director of Environmental Studies, with the assistance of Mr. H. Theodore Heintz, Jr., Senior Economic Consultant, and Mr. Gerald C. Horak, Staff Scientist. Ms. Anita Calcote was responsible for typing and production of the report. Valuable guidance on content and format was provided by Mr. Thomas E. Waddell, the U.S. EPA Project Officer.

ABSTRACT

This report provides a critical review of the current state of the art and future prospects of estimating benefits of air and water pollution control. Benefits of controlling air and water pollution arise from gains resulting from improvements in air and water quality. Such gains can be the reduction of damages caused by pollution or the increase in options now feasible because of improved environmental quality.

This report represents three independent critiques by three experts. Benefit assessment methodologies were evaluated for the following benefits categories: human health, recreation and aesthetic properties, productivity, materials, and natural ecosystem perturbations. Specific aspects discussed include the nature and role of benefits, damage functions, valuation of effects, aggregation of results, and representation of uncertainties.

The conceptual foundations of estimating pollution control benefits were presented and compared with empirical studies. It was concluded that while available estimates often do not adequately reflect the state of the art, estimates of pollution control benefits would potentially be very useful to decision makers. The conceptual basis provided by economic theory for benefit estimation is adequate in most respects and far ahead of the corresponding empirical effort. A number of studies are guilty of failing to list explicitly critical assumptions or to express adequately uncertainty in the results, while other studies have employed conceptual models that are inappropriate to the problem at hand or the available data. It was also concluded that damage functions underlying benefit estimates are frequently based on insufficient data and/or inadequate characterization of exposure and effects. National benefits estimates were found to be based on regional studies which are frequently inadequate in number and/or quality.

For improving general estimation of benefits it is recommended that funding for benefits estimation research be reassessed in light of its potential utility to decision-making process, that a comprehensive national plan for closely coordinated regional benefit studies be developed and implemented and that *ex post* evaluation of pollution control benefits gained through past and current control programs be conducted.

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I. OVERVIEW

This first chapter presents a general overview of the state-of-the-art in estimating benefits of air and water pollution control. The material is based on the three papers that follow, as well as other sources referenced at the end of this chapter (Heintz et al., 1976 and Waddell, 1974). References to specific material in the three papers are given, wherever appropriate, to direct the reader to additional information. This chapter is covered under the headings: purpose and scope, conceptual foundations, air quality benefits, and water quality benefits.

A. PURPOSE AND SCOPE

This section sets the scene for subsequent discussion by presenting the background for this study, its purpose and scope, and the plan of work.

1. Background

Nearly everyone is now satisfied that there exists a causal relationship between environmental pollution and certain damages suffered by society. These may take the form of increased incidence and prevalence of disease, diminished recreational experience, decreased property values, reduced crop yields, more frequent maintenance and replacement of exposed materials, and other, less well-identified losses. This being the case, a reduction in pollution levels should bring about a corresponding decrease in these damages and produce a set of benefits equivalent to the difference in damages before and after the reduction took place.

Legislators, planning officials, and other environmental decision makers are frequently faced with the decision of how much to reduce pollutant levels, in the light of the associated direct costs of pollution control and possible secondary economic impacts. In the past, the rationale for these decisions was rather obvious, in that they were often made in response to popular sentiment. However, as economic conditions have changed for the economy as a whole, as well as for certain industries, the costs have become more acutely felt, especially in the wake of the energy crisis. At the same time, the beneficial effects of reduced, or stable, pollution levels were neither obvious, nor easily measured. Clearly, the decision makers would need a more sensitive tool for comparing and trading off the costs and benefits of various levels and types of pollution control.

It was this need that gave birth to increased interest in environmental benefit/cost or tradeoff analysis, including, benefit assessment research. Admittedly, this research is an inexact science, primarily because the underlying biological and physical relationships need considerable additional research and because social benefits and costs are diffuse and frequently difficult to quantify, much less to express in monetary terms. Even so, the process of logical and systematic scrutiny inherent in benefit/cost analysis can contribute substantially to the ability of decision makers to improve the social welfare through more efficient allocation of the limited resources of the public treasury.

This potential contribution of tradeoff analysis was apparently recognized by the framers of the National Environmental Policy Act of 1969 (PL 91-190), primarily in Sections 102 and 204. Section 102 calls for the "identification and development of methods and procedures which will ensure that presently unquantified environmental amenities and values may be given appropriate consideration in decision making, along with economic and technical considerations." Section 204 charges the Council on Environmental Quality (CEQ) to gather, analyze, and interpret timely and authoritative information concerning the conditions and trends in the quality of the environment.

In recent years, there have been a number of estimates of the benefits of air and water pollution control. Among the most notable were the reports on air and water pollution by Waddell (1974) and Unger *et al.* (1974), respectively. More recent estimates are reported in CEQ's annual report, *Environmental Quality - 1975*. However, there seems to be a widespread skepticism about the validity of available benefit estimates.

With the recent reorganization of the U.S. EPA's Office of Research and Development, the benefits assessment program is being reevaluated. This report should serve as valuable input into the evaluation and re-direction of the benefits research.

2. Purpose and Scope

The purpose of this project is to assit decision makers in U.S. EPA and other Federal agencies by providing a critical review of the current state of the art and future prospects of estimating benefits of air and water pollution control. This should prove valuable in allocating limited pollution control resources; assessing the prospects for further benefits research; and in scoping out a viable benefits research effort.

The specific objectives of this effort are as follows:

- To assess the current state of the art in estimating benefits of air and water pollution control, including validity and accuracy of techniques and data
- To assess the future prospects of benefit estimation
- To identify fruitful areas for additional research.

The scope of this effort can be formulated in terms of the pollutants, benefit categories, affected populations, geographic areas, and time horizon. The benefit categories for air and water pollution are listed below:

Air pollution:

- Human health
- Vegetation
- Materials
- Aesthetics
- Other (animals, ecological risks, etc.)

Water pollution:

- Human health
- Production (municipal, industrial, and agricultural supplies; commercial fisheries and materials)
- Recreation
- Aesthetics and property values

The remainder of this chapter discusses the conceptual foundation of estimating pollution control benefits and summarizes air and water quality benefit discussions as presented in the subsequent chapters.

B. CONCEPTUAL FOUNDATIONS

This section addresses the conceptual foundation of estimating pollution control benefits as presented in the three papers. Detailed references to the papers are provided throughout. The topical headings are: nature and role of benefits, damage functions, valuation of effects, aggregation of results, representation of uncertainties, and conclusions and recommendations.

1. Nature and Role of Benefits

Benefits of controlling air and water pollution arise from gains resulting from improvements in air and water quality. Such gains can be the reduction of damages caused by pollution or the increase in options now feasible because of improved environmental quality. The corresponding economic damages result in "out of pocket" losses by increasing the costs of using air and water, by decreasing their use or activities depending on their use, and by increasing the costs of avoiding or repairing the effects of pollution. A basic concept in benefit evaluation is "willingness to pay," defined as the highest price that individuals would be willing to pay to obtain the improvement in air or water quality resulting from a given pollution control program. Economists prefer to evaluate benefits in monetary terms, because this provides a common measure of all types of benefits and costs.

However, many types of damages are not amenable to quantification in monetary terms, because of their nature and the state-of-the-art of available measurement methods. These difficult-to-measure benefits probably account for a substantial portion of the total value of pollution control to society. This is the case with "psychic" damages, so labeled because they relate to the pleasure or displeasure associated with the use of the environment. Psychic damages include decreased pleasure and increased pain and anxiety from the use of polluted air or water, as well as the loss of non-user values.

Non-user values arise with people who have no immediate plans of making direct use of an environmental amenity, but are nevertheless willing to pay for its preservation for a variety of reasons. In the case of option value, they wish to ensure an option of being able to use it in the future. Vicarious or bequest values describe the benefits experienced by people who would provide these environmental amenities to their heirs or others. Preservation value is associated with the desire to preserve a unique natural resource. Finally, risk aversion refers to the willingness of people to pay for decreasing or averting the risk of a catastrophic or irreversible damage, such as the flooding of arable, land or extinction of a biological species. (Heintz, Hershaft, Horak, 1976).

Over time, as the underlying benefit analyses become more reliable, estimates of pollution control benefits should provide for establishment of more efficient environmental policies. However, equity considerations, as well as various political, institutional, and technical issues also enter into the decision making process. A thorough tradeoff analysis would integrate all of these factors.

Other contributions of benefit estimation may be listed as follows (Chapter II pp. 6-8; IV 3-4):

- Enhanced understanding of the problem, the underlying factors, and potential solutions
- Development of an analytical framework for entering inputs from other sources
- Establishment of reasonable environmental quality standards.

Estimation of pollution control benefits ideally should follow the sequence of steps listed below (Heintz <u>et al.,</u> 1976; II 53-65):

- Project pollutant emissions on the basis of population levels and economic activity for the area and time period under consideration
- Estimate reduction of pollutant emissions attributable to implementation of given control policy

- Estimate improvements in environmental quality associated with stipulated reduction of emissions
- Estimate reduction in adverse effects associated with improvement in environmental quality
- Estimate regional benefits (in monetary terms if possible) of reductions in adverse effects and other considerations
- Extrapolate and aggregate regional benefit estimates across all relevant regions and time periods of interest to obtain national estimates.

The first two steps involve the projection of a suitable economic scenario and evaluation of the cost-effectiveness of various administrative and technological pollution control fixes. The third step requires the use of complex models of the diffusion and assimilation of specific pollutants within their respective media. The remaining steps rely on (1) the development of damage functions and (2) economic benefit analysis. These two topics form the basis of this report and receive closer scrutiny in the pages that follow.

2. Damage Functions

Damage functions provide a quantitative expression of the relationship between exposure to specific pollutants. The type and extent of the associated effect can then be estimated based on a target population, or "population at risk". Despite their crucial role in the formulation of benefits of pollution control, damage functions have been treated lightly in the three papers that follow (Chapters II, III and IV), because the essence of damage functions is more physical and biological than economic. Thus, most of the material presented in this section is abstracted from Hershaft et al. (1976).

A typical S-shaped damage function, showing the damage corresponding to a given exposure to a specific pollutant, is presented in Figure I-1. The ordinate may represent either the number of individuals affected or severity of effect. The abscissa indicates the dosage in terms of time at a given ambient concentration, or in terms of ambient concentration for a fixed period of time. The lower portion of the curve suggests that, up to a certain exposure value, known as a "threshold level", no damage is observed, while the upper portion indicates that there exists a damage saturation level (e.g., total destruction of the target population) beyond which increased exposure levels do not produce additional damage. The middle, quasi-linear portion is very useful in that any data points here can be readily interpolated, and the frequent assumption about linearity of a damage function is most valid in this sector.

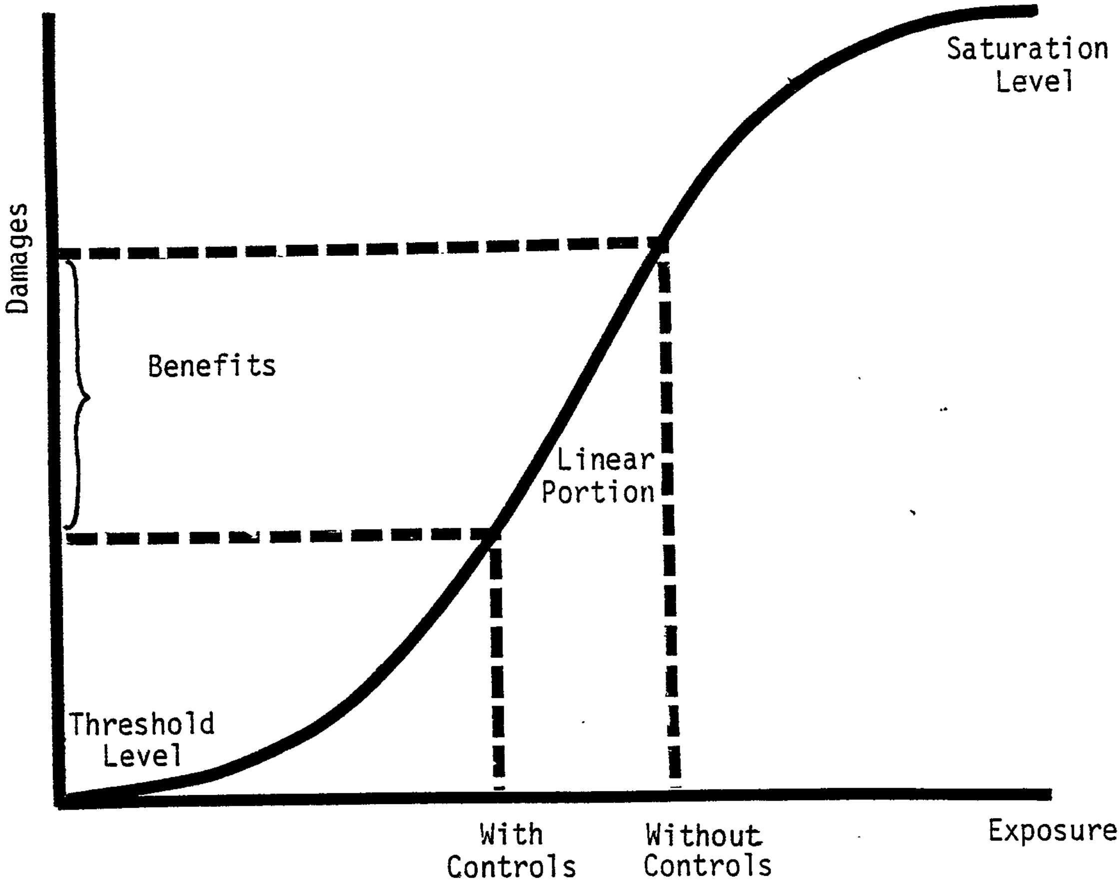

Figure I-1. Hypothetical Damage Function

Exposure is typically measured in terms of ambient concentration levels and their duration and it may be expressed as "dosage" or "dose". Dosage is the integral of the time and ambient concentration to which the subject has been exposed, whereas dose represents that portion of the dosage that has been actually instrumental in producing the observed damage. The damage can become manifest in a number of ways and can be expressed in either physical and biological, behavioral response, or economic terms. If the effect is physical or biological, the resultant relationship is known as a physical or biological damage function, or a dose-effect function. In an economic damage function, on the other hand, the effect is expressed in monetary terms. Economic damage functions can be developed by assigning dollar values to the effects of a physical or biological damage function, or by direct correlation of economic damages with ambient pollutant levels.

In reporting a damage function, one needs to specify the pollutant (or surrogate), the dose rate, the effect, and the "population at risk". Dose rate, or the rate at which ambient concentration varies with time, has a major influence on the nature and severity of the resultant effect. For example, long-term exposure to relatively low concentrations of air pollutants may result in manifestations of chronic disease, characterized by extended duration of development, delayed detection, and long prevalence. Short-term exposure to high concentration levels, on the other hand, may produce acute symptoms, characterized by quick response and ready detection, as well as chronic cumulative, or delayed effects.

Specification of the population at risk involves the characterization of the nature and magnitude of the exposed population. Damage functions, when extrapolated on the basis of population at risk, serve to define the total damages produced by a given level of exposure by multiplying the corresponding unit damage (e.g., increased mortality) for the specified population at risk (e.g., white males over 65) by the total number of units within this population. Detailed population characteristics also permit investigators to adjust their results to reflect the influence of various intrinsic (e.g., age, race, sex) and extrinsic (e.g., general health, occupation, income, and education) variables in assessing the specific effects of air pollutants (e.g., increased incidence of lung cancer). Finally, population-at-risk information can provide useful guidance for allocating pollution control resources by identifying areas with particularly susceptible populations exposed to relatively hazardous levels of pollutants. (Takacs and Shea, 1975).

The data required to develop physical or biological damage functions are obtained primarily through epidemiological, field, clinical, toxicological, or other laboratory investigations. The first approach involves the comparative examination of the effects of pollutants on selected segments of population exposed to different levels of pollution, in order to deduce the nature and magnitude of the likely effect. Field observations represent a similar approach to assessment of effects on animals, vegetation, and materials, and they are characterized by similar analytical techniques and concerns. Clinical studies are concerned with the effects of exposure on human subjects. Toxicological investigations involve deliberate administration of controlled doses of pollutants to animal, and occasionally, human subjects, and observation of the resulting effects. Laboratory studies represent essentially the same approach for determining effects of pollutants on plants and materials.

The three principal techniques for analyzing the relationship between exposure and effect indices in epidemiological studies are known as cross tabulation, multivariate regression, and non-parametric or distribution-free analysis. Cross tabulation is the simplest of the three. Multivariate regression provides a rapid indication of the degree of association between a large number of independent and dependent variables and is readily programmable for computer operation. However, its validity is heavily contingent on a fairly precise *a priori* definition of the relationship between each independent and the dependent variables and on precise measurement of the independent variables. Thus, this technique is especially vulnerable to the poor precision in measurement and reporting of air pollution levels, for example, for a given segment of population. Non-parametric analysis, on the other hand, is free of these assumptions, but requires laborious data reduction for each of the many pairs of independent and dependent variables and interposition of expert judgment at each step of the process.

In the development of damage functions on the basis of epidemiological or field studies, it is important, albeit complex, to isolate or control the influence of cofactors and covariates. The former may be defined as factors that act in concert with the independent variables (e.g., relative humidity or cigarette smoking and pollutant level). Covariates, on the other hand, may be thought of as factors that vary jointly with the principal dependent variable. The interference of cofactors and covariates with results of the analysis can be reduced by holding them constant or with the aid of statistical techniques. When this cannot be done, it is frequently assumed that the distribution of these factors in the target population is sufficiently uniform to avoid vitiating the basic conclusions.

Finally, it should be noted that epidemiological and field studies and observations can only indicate an association between exposure to pollution and the observed effect, suggesting the existence of a causal relationship. Such a relationship can then be tested by clinical, toxicological and laboratory studies.

3. Valuation of Effects

Estimation of economic benefits of a given improvement in environmental quality involves either conversion of the associated reduction of adverse physical and biological effects into monetary terms, or direct determination of the user's willingness to pay for the improvement. The three common methods to estimating benefits of pollution control are:

- Alternative cost
- Opportunity cost
- Willingness to pay.

The alternative cost method is employed most frequently, because of its rapid applicability and avoidance of complex economic analysis. This involves development of a damage function, leading to estimation of the total damages corresponding to exposure of the target population over a specified period. Because there is no provision for substitution or any other mitigative adjustment by the target population, the damage estimate may be excessive. (III 16).

Opportunity cost on the other hand, is estimated on the basis of the cost of substitution and other adjustment opportunities open to the target population. This formulation presumes that ownership to the environmental good is held by the target population, which is then entitled to trade it away for a substitute good.

Finally, the willingness-to-pay method is based on the determination of how much the affected population is willing to pay to avoid the particular environmental degradation. Here, the title is presumed to be vested in the perpetrators of environmental degradation, rather than the target population. (III 17).

An alternative formulation of approaches to estimation of pollution control benefits is as follows (IV 5-6):

- Market prices, if a market for these goods and services exists and the additional output does not affect price significantly

- Simulated market prices (especially useful for estimation of recreation and aesthetic benefits)

- Changes in net income of producers for consumers, if outcome represents an intermediate good (useful for production benefits)

- Cost of most likely alternatives for obtaining same objective.

In spite of general reliance on simulated markets, some market price data are also useful in estimation of benefits. These data need to be germane, relatively free of price imperfections, and adjusted to long-term expected levels. Technological externalities should be included and monetary externalities should be excluded in estimating these benefits. Finally, the annual changes in benefit streams should be identified for the various benefit categories. (IV 5-9).

Estimation of benefits on the basis of willingness to pay entails the intermediate steps of estimating changes in user behavior associated with anticipated reductions in the adverse effect and the marginal willingness to pay associated with these changes. Changes in user behavior reflect the user's perception of environmental quality. Moreover, they are affected by local socioeconomic conditions. (IV 10-11).

The benefits associated with a change in environmental quality are defined by the area under the demand curve over the applicable range, but, since environmental amenities are generally not bought and sold in the marketplace, there may not be any direct way of estimating the shape of the demand curve by conventional econometric techniques. Instead, discreet market values may need to be inferred from individual responses to changes in environmental quality. The techniques for drawing these inferences are known as market demand analysis, net productivity, net factor income, travel cost studies, land value studies, and personal interviews. (II 15-16).

Another representation of the relationship between changes in environmental quality and the user's utility or welfare is known as "consumer's surplus". This is defined as the difference between what an individual is willing to pay and the market price. Determination of consumer's surplus can be affected by an alternative formulation of the problem. (III 9-10).

An important element in estimation of pollution control benefits is the aversion of grave environmental risks brought about by pollution. The value of risk aversion can be measured through observation of individual behavior, or through lottery games. The first method is preferred, because it is more realistic, permits construction and testing of behavior models, and provides for application of opportunity cost or willingness-to-pay formulations. (III. 19-21).

In closing this discussion, it is important to bear in mind that the data required to implement these valuation steps are frequently difficult to obtain and that some of the economic concepts, such as the value of human life, or, non-user benefits, have not been adequately defined. Thus, judgmental estimates need to be frequently substituted for hard data and a balance must be struck between the desirable and available data and techniques. In such cases, it is very important to state explicitly all assumptions, the reasons for their selection, and the implications of choosing different assumptions. Otherwise, the estimate can easily be misleading and discredit the entire benefit estimation process. (II 5-8).

Usefulness of benefit estimates is governed by their adherence to the following provisions (II 9-11):

- Consistent terminology
- Clearly defined pollutant levels
- Clearly identified pollutants and sources
- Appropriate degree of detail
- Clearly defined relationships between pollutant levels and human values.

The term "costs" should apply to pollution control resources; "damages" should refer to the total loss to society due to a polluted environment; "benefits" should represent the gains realized by society from a given improvement in environmental quality. Similarly, the quality levels being compared should be already defined as those "with" and "without" controls, rather than those "before" and "after" applications of controls, to avoid time-related complications, such as inflation. (II 9-10).

The pertinent pollutants and their sources should be clearly identified with the environmental improvement sought, to avoid gaps and overlaps in the estimation procedure. Moreover, policy decisions should be based primarily on marginal benefits associated with efects of the particular decision, rather than on average or total benefits that would accrue in the absence of pollution. (II 9-10).

Benefit estimates corresponding to a given environmental improvement should be expressed in monetary terms and should be based on individual behavior and preference. Empirical measures and techniques should be appropriate to the specified theoretical model and available data. Finally, these estimates should reflect the regional and temporal variations in both economic and environmental variables. (II 9-11, 34-35).

The type and degree of geographic, temporal, and economic detail should be tailored to the specific needs of the user. For example, only a rough estimate may be needed to make an initial decision, with more detailed estimates being provided for more refined future decisions. (II 11).

4. Aggregation of Results

Most benefit estimation studies address a specific geographic location, group of pollutants, population at risk, and time period. Extension of these results to the national level and some future time frame requires the aggregation of the regional estimates and projection of a number of variables, including ambient levels, populations at risk, personal incomes, and costs of damages. In aggregating over several variables, it is important to specify the order in which the variables are being aggregated. (III 24-28).

The benefit categories for which the data are collected are often dictated by availability of information sources and analytical expediency, rather than the needs for a uniform and self-consistent framework. Consequently, different studies evaluate damages that are not necessarily additive, or even comparable, and careful interpretive techniques must be applied to the results of such studies to prevent gross overlaps or omissions of damage estimates. Moreover, in aggregating such fractional results, it has not been possible to reflect the potential impacts of changes in individual components on one another, nor the impact of the general adjustments of the economy and the resulting reduction in damages. (Heintz et al., 1976).

Aggregation of benefit estimates entails a tradeoff of detailed information about form and structure in return for treatability and ease of comprehension. Attempts to apply aggregated national estimates to local pollution control decisions can introduce substantial errors, because the information lost in the aggregation process cannot be recovered. In principle, national estimates may be developed directly, rather than by aggregation of local studies. (III 24-28). However, additional research in this area is necessary.

Overlaps and gaps between categories of benefits may arise when two types of effects (e.g., health effects and property values, in the case of air pollution, and recreation benefits and property values, in the case of water pollution) are estimated by different methods which may count the same benefit component twice or fail to capture certain other components. It is important, therefore, to attempt removal of the excess count and to inpute a value for the missing component. Another problem is the inconsistency in quality of estimates for different benefits categories. (II 20-23; IV 13-14).

If the benefits of interest accrue over a number of years, then it may be useful to compute the present value of the total stream of benefits with the aid of an appropriate discount rate and time horizon. This approach becomes less effective when the projected effects extend over a very long time period that spans several generations (intergenerational effects), because of the large reduction factor. For example, using a discount rate of 5 percent, the current benefit of an effect occurring 200 years hence is reduced by a factor of

6×10^{-4}. In such cases, the consideration of intergenerational equity should outweigh that of intertemporal efficiency. Another problem in computing the present value of the stream of benefits is the differential growth rates. (II 23-24; IV 13-14).

5. Representation of Uncertainties

Uncertainties about benefit estimates arise from errors in the four intermediate steps of the estimation process:

- Specification
- Measurement
- Valuation
- Aggregation.

Errors of aggregation are associated with attempts to extrapolate national values from regional estimates or future values from current or past estimates. They arise from geographic and temporal variability of user behavior and market conditions. Errors of valuation are due to the difficulty of assigning monetary values to certain physical, biological, aesthetic, or psychic effects. (III 22-23).

Errors of specification include any type of error in specifying the functional form of the relationship under study or in accounting for important variables. A particularly common and grave error of specification is committed in attempting to extrapolate a complete functional relationship from a few data points that are barely adequate to characterize a small portion of the curve. Even if one were willing to make an assumption about the overall shape of the function, there is frequently no way of knowing which portion is represented by these data points. (Hershaft et al., 1976).

Errors of measurement may be incurred in the course of the following steps of the benefit estimation process:

- Location of monitoring station and subjects
- Sampling and analysis

- Averaging and aggregation of ambient pollutant levels
- Determination of effect
- Impact of covariates
- Characterization of population at risk.

If the errors of measurement of the independent variable are relatively small, occur at random, and follow a normal, or Gaussian distribution about the mean value of each variable, then the total error of all the independent variables can be computed by standard statistical techniques. However, this is seldom the case, because measurement of such independent variables as pollutant level, meteorological conditions, and socioeconomic characteristics is subject to errors that are both large and biased. The advantages of this statistical approach include an opportunity to incorporate more information in the reported results and the assignment of a probability to the various outcomes. (Hershaft et al., 1976; II 24-26; III 23-24).

Envelopes characterizing errors and uncertainties of benefit estimates can be also obtained by more practical means, including:

- Replicating a specific study using new data or methods
- Providing ranges of values of the more important variables
- Combining results of several studies
- Applying "best" and "worst" case assumptions.

Replication and data manipulation are essentially empirical techniques of determining the errors and corresponding confidence bands. Combining the results of several studies is a rare and uncertain opportunity, in light of the great variety of conditions and populations that often characterize the different efforts. Application of "best" and "worst" case assumptions is more an argumentative than a statistical technique. The lower boundary, or best case, is established by attributing all reasonable portions of the effect to any plausible cofactors and covariates and associating only the residual effects with pollutant exposure. The upper boundary, or worst case, is determined by inverting this procedure and assuming a minimal impact of other variables. (Hershaft et al., 1976).

6. Conclusions and Recommendations

A number of major conclusions emerge from the discussion of conceptual foundations of estimating pollution control benefits:

- Estimates of pollution control benefits would potentially be very useful to decision makers (II 46)
- However, available estimates do not adequately reflect the state of the art (II 48)
- The conceptual basis provided by economic theory for benefit estimation is adequate in most respects and far ahead of the corresponding empirical effort (II 46)
- Nevertheless, a number of studies have employed conceptual models that are inappropriate to the problem at hand or the available data
- A number of studies have failed to list explicitly critical assumptions or to express adequately uncertainty in the results
- National benefit estimates are based on regional studies which are frequently inadequate in number and/or quality
- Damage functions underlying benefit estimates are frequently based on insufficient data and/or inadequate characterization of exposure and effects (II 27-30)
- Benefits assessment research has been accorded a relatively low priority by the U.S. Environmental Protection Agency, perhaps because of skepticism about its value, or the public health and ecosystems focus of environmental legislation (III 40-41)
- Past U.S. EPA research strategy has been characterized by short-term, piecemeal studies which are not conducive to the accumulation of a consistent and comprehensive data base useful in decision making (III 41-42)

- Some aspects of benefit estimation are subject to value and equity judgments, rather than application of economic theory (II 47-48; IV 13-15)

  - relative merits of different distributions of benefits among population groups

  - adverse consequences of present actions on future generations

Recommendations for improving general estimation of benefits are as follows:

- Reassess funding for benefits estimation research in light of its potential utility to decision-making process and the uncertainties permeating other, currently funded national assessment programs (III 41-42)

- Develop and implement a comprehensive national plan for closely coordinated regional benefit studies that is well grounded in economic theory and provides for consistent aggregation and expression of the uncertainty of all estimates (III 42)

- Develop and implement a comprehensive program of *ex post* evaluation of pollution control benefits gained through past and current control resources (II 53)

- Convene a group of experts every few years to develop comprehensive estimates of national benefits of pollution control (II 52)

- Employ scientists from other disciplines in planning and implementing benefits estimation studies (IV 25).

C. AIR QUALITY BENEFITS

This section presents an overview of the discussion on benefits of air pollution control contained primarily in Chapter III. Specific references to this chapter are provided wherever appropriate. The topics covered are: current estimates, health benefits, aesthetic benefits, vegetation and materials benefits, and recommendations.

1. Current Estimates

The latest estimates of national air pollution damages have been compiled by Heintz et al. (1976). These are equivalent to benefits that would accrue annually from reduction of air pollution to threshold levels. Table I-1 summarizes the benefit estimates for the four major classes of benefits, in terms of best estimates and corresponding ranges. The latter were derived largely through a proportional representation of the ranges quoted by Waddell (1974).

Table I-1. Estimated National Damages of Air Pollution for 1973 ($ billion)

Damage Category	Best Estimate	Range Low	Range High
Health	5.7	2.0	9.4
Aesthetic	9.7	5.7	13.7
Vegetation	2.9	1.0	9.6
Materials	1.9	0.8	2.7
Total	20.2	9.5	35.4

Source: Heintz et al., 1976

To gain a proper perspective of these estimates, it is important to recognize that they do not reflect all of the potential damages from air pollution. There are a number of categories of potential damages for which estimates are not available. The most important of these is the threat to preservation of the natural environment, including unique ecosystems and species. But, even within the categories for which estimates are available, the existing monetary measures tend to understate the total damages. For example, the estimated health damages reflect the direct and indirect costs of illness, such as health care costs and lost earnings, but do not reflect the value of lost leisure time or the psychic cost of illness and death.

In combining estimates from different classes of damages, care has been taken to minimize double counting. For example, studies of the differences in residental property values associated with differences in air pollution reflect primarily the aesthetic and soiling effects, rather than health effects. This is based on the argument that the aesthetic effects are experienced directly in everyday life, whereas health effects are mostly long-term, and are not distinguishable by the general population from other causes of illness. Although improved education may be altering people's awareness of the health effects of air pollution, it is not likely that this has been significantly reflected in past property values, on which these benefit estimates have been based.

The damage estimates presented here are based on the interpretation of the results of numerous studies of varying scope, methodology, and data quality. The availability and reliability of information from these studies is indicated in Table I-2. It will be noted that effects data are most available for effects of SO_x, oxidants, and particulates and for the damage categories of human health and vegetation.

Table I-2. Availability and Reliability of Information on Air Pollution Damages

Damage Categories	NO_x	Oxi-dants	SO_x	CO	HC's	Parti-culates	Other
Human Health	SF	SF	IG	SG	SF	IG	IF
Aesthetics	U	SF	IG	U	U	IF	U
Vegetation	IF	IG	IF	SG	SF	SF	SF
Materials	SF	IF	IG	SP	SP	SG	U

Source: Heintz et al., 1976

Availability	Reliability
A - ample	E - excellent
I - insufficient	G - good
S - scarce	F - fair
U - unavailable	P - poor

2. Health Benefits

The key consideration in estimation of health benefits of air pollution control is the valuation of human life. This can be accomplished by the Thaler-Rosen or the productivity method. The former estimates the average value of human life as somewhat in excess of $200,000 on the basis of individual preference for higher wages versus more risky occupations. The problem with this method lies in the fact that willingness to pay for preservation of human life rises steeply with proximity of death. (II 17-18).

The productivity, or human capital method values each life at the present value of the expected stream of the individual's future earnings. The difficulties here are the conversion of a probabilistic estimate into a specific stream of earnings and the failure to value lives of people who receive no compensation for their labor (e.g., housewives, children, retirees, volunteers). It should be noted also that there is no logical connection between value of future earnings and willingness to pay. (II 18-19).

The household production function is an analytical framework that can be applied in estimating health benefits of pollution control. This theory views the consumer as combining market purchased goods and his own resources to produce a given state of health. The major advantage of this method is that it provides for dealing with the inadequacies of previous methods, such as failure to take into account the value of leisure and uncompensated time as well as individual adjustment to pollution. (III 31-32).

3. Aesthetic Benefits

Estimation of aesthetic benefits of air pollution control encompasses a number of the concepts discussed in Section B. This is illustrated in Chapter III Attachment, which discusses a case study involving the impact of air pollution on the outdoor recreational market in San Bernardino, California. These concepts may be described as (III 46-54):

- Multidimensional heterogeneity
- Cost of market participation
- Institutional and temporal constraints.

The first term refers to the fact that outdoor recreational sites exhibit substantial differences in a number of dimensions (e.g., size, topography, vegetation, facilities, congestion, accessibility). The second concept deals with the relatively high cost of participating in the outdoor recreation market due to travel requirements, search for a suitable site, and purchase of special implements (e.g., hiking boots and backpacks). Finally, the market is subject to a number of controls exercised by public institutions, such as health and safety regulations and restrictions on attendance, as well as constraints on the time schedule available for recreation. (III 49-53).

Another aspect of aesthetic benefits is reflected in property values. An improved method of obtaining an aggregated national estimate of property value changes has been developed. This method does not assume that the same set of weights applied to each locale, time period, and household, nor does it ignore the manner of distribution. Moreover, it is soundly grounded in economic theory and is capable of capturing several elusive features of the market. (III 29-30).

4. Vegetation and Materials Benefits

Estimates of air pollution damages to agricultural crops have focused on the physical measures of damage and have ignored the effect of the resulting changes in output on the unit price. Yet, models of agricultural markets that are capable of capturing these price effects are generally available and should be applied to the estimation of crop damages (III 36).

Past studies of production damages of air pollution have focused on materials damages and have neglected the involvement of these inputs in the production process. It appears desirable, in this connection, to assess the effects of air pollution on labor supply and productivity. The findings should be transferable to other cases of occupational exposure. (III 33).

Past attempts to construct indices of air pollution control benefits failed, because they viewed benefit changes as nearly synonymous with changes in ambient concentrations, and social valuations were based almost exclusively on air quality standards. This representation could be improved by viewing ambient quality as a factor of production, e.g., changes in morbidity characteristics associated with certain pollutant levels. (III 34).

Results of interviews to ascertain individual preferences are frequently biased by the interviewees anticipation of how their responses will be used. Nevertheless, differences in willingness to pay for various pollution levels may provide a valid representation of the marginal willingness to pay, which is of primary importance in policy decisions. Moreover, techniques have been developed for eliciting truthful responses about preference orderings. (III 35-36).

5. Recommendations

The following research projects are recommended to improve estimation of air pollution control benefits:

- Apply the household production function framework to obtain health benefits of pollution control (III 31-32)
- Conduct research on value of human life along two approaches (II 50):
  - determination of willingness to pay for small changes in probability of death
  - determination of the value implicit in public decisions involving public safety
- Assess effects of air pollution on labor supply and productivity (III 32-33)
- Prepare improved estimates of benefits derived from available property value studies and conduct new studies (II 5.2; III 29-30)
- Apply available models of agricultural markets to estimation of crop damages (III 36)
- Investigate improved methods of assessing willingness to pay through interviews (III 35-36).

Benefit estimation would also gain from the following recommendations designed to improve development of air pollution damage functions (Hershaft et al., 1976).

- Determine how well air quality measurements at the monitoring station represent the ambient quality affecting the population at risk
- Determine the impact of mobility and shielding of the subjects on their exposure

- Develop a composite index of exposure representing both prevailing and extreme values

- Define current air quality monitoring requirements for potential future damage studies

- Assess and improve the accuracy and reliability of various methods for determining morbidity

- Develop a method for determining changes in life expectancy due to exposure to air pollutants

- Provide uniform guidance for designing studies of the effects of air pollutants on vegetation

- Conduct studies on the following effects of air pollutants:

  - specific effects of NO_2 and nitrates

  - specific effects of different types of sulfates

  - chronic effects of low-level exposures to specific pollutants

  - carcinogenic, teratogenic, and mutagenic effects of specific pollutants

  - effect of oxidants on yields of major crops

  - effects on paints, cement, rubber, plastics, and wood

  - effects on climate and local weather conditions.

D. WATER QUALITY BENEFITS

This section presents an overview of the discussion on benefits of water pollution control contained primarily in Chapter IV. Again, specific references to this chapter are provided wherever appropriate. The topics covered are: current estimates, recreation benefits, aesthetic and ecological benefits, health benefits, production benefits, and conclusions and recommendations.

1. Current Estimates

The latest estimates of national water pollution damages have been compiled by Heintz et al. (1976). These are equivalent to benefits that would accrue annually from reduction of water pollution to "threshold" levels. Table I-3 summarizes these estimates for four major classes of damages, in terms of best estimates and the corresponding ranges. The latter reflect the substantial uncertainty associated with these estimates.

Table I-3. Estimated National Damages of Water Pollution for 1973 ($ billions)

Damage Category	Best Estimate	Range Low	Range High
Outdoor Recreation	6.3	2.5	12.6
Aesthetic and Ecological	1.5	0.6	2.8
Health	0.6	0.3	1.0
Production (including municipal, industrial, agricultural supplies, commercial fisheries, and materials damage)	1.7	1.1	2.3
Total	10.1	4.5	18.7

Source: Heintz et al., 1976

Since the largest damages are in the recreational, aesthetic, and ecological categories, the total estimates strongly reflect the uncertainties inherent in the currently available data and techniques for estimating the monetary value of these uses of water. The estimation of recreation damages depends upon understanding the behavior of recreationists when confronted with a complex set of choices concerning types of recreation, travel, sites, and the quality of the recreational experience. In determining aesthetic and ecological damages, it is necessary to consider the value which individuals place on viewing or preserving waterways of high quality.

A broad spectrum of studies have been reviewed to obtain information on water pollution control damages. Table I-4 reports on the availability and reliability of the information contained in these studies.

Table I-4. Availability and Reliability of Information on Water Pollution Damages

Pollutant	Outdoor Recreation	Aesthetic and Ecological	Health	Production Losses
Acidity	SF	U	U	SP
BOD	IF	SP	U	IF
Coliform Bacteria	SF	U	SP	SP
Floating Solids	IF	U	U	SP
Hardness	U	U	U	IP
Nutrients	SP	U	U	SP
Odor	U	U	U	U
Oil	SP	SP	U	SP
Pesticides	U	U	U	U
Sediment	IF	IF	U	IF
Temperature	IF	SP	U	SP
TDS and Salinity	U	U	U	IF
TSS and Turbidity	SF	U	U	SP
Toxic Metals	SP	U	U	SP
General Pollution	AF	SP	SP	IF

Source: Heintz _et al_., 1976

Availability:

A - ample
I - insufficient
S - scarce
U - unavailable

Reliability:

E - excellent
G - good
F - fair
P - poor

2. Recreational Benefits

Estimates of recreational benefits are based largely on studies of the behavior of recreationists faced with changing water quality. The analysis attempts to predict how recreational patterns and the resulting values gained by recreationists would be affected by changes in water quality parameters., Unfortunately, damage functions relating these changes are very sketchy. (IV 11, 20).

Most national benefit estimates are based on a few partial studies of local recreational patterns. This presents two sources of uncertainty. First, there is considerable variation in the relationship between water quality and consumer behavior from one geographic location to another. Second, local studies cannot account for the large number of options open to the recreationist, i.e., how deterioration of water quality at one site affects his behavior at other sites. (IV 19-20).

Two other points are worth noting. Most studies consider only two pollution levels: the current and the one meeting water quality standards. Instead, a range of pollution levels should be examined to determine that level where marginal costs become equal to marginal benefits. In addition to the usual efficiency grounds, improvement of water quality for recreation could be justified on other grounds, such as compensation to those who can not afford to recreate elsewhere, preservation of future options, and national pride. (IV 20-21).

Water pollution affects recreation by reducing the quality of the recreational experience, by causing the consumer to recreate less often, and by causing him to incur higher travel costs to enjoy substitute sites. The last of these components is measured most readily. However, the use of travel costs for this purpose is susceptible to the following complications (IV 21-22):

- Unusual income elasticities
- Impact on travel of highway construction, crowding, and gasoline prices
- Inertia in recreational preference
- Transfer of recreation from a more distant, but more desirable site to a closer site, as a result of pollution of the distant site.

Two conceptual models estimating national recreational benefits by aggregation of site and situation-specific results have been developed. The first examines the conceptual links between quality, quantity, and price of the recreational experience. The second model demonstrates the usefulness of a "reduction in travel cost" construct and specifies data requirements. (IV 23-24, Attachment A and B).

3. Aesthetic Benefits

The state of the art in estimating aesthetic and ecological benefits is even more limited than that for estimating the recreational benefits. Effect of water quality on aesthetic and ecological concerns and the resultant consumer behavior modification are difficult to measure, because they are not well reflected in market transactions. Consequently, such estimates are based on personal interviews which seek to determine the value placed by consumers on these concerns. It is widely suspected that the interviewees are attempting to affect the results of the interview by their responses, i.e., that there is a substantial disparity between what they say they would do and what they would actually do. Although psychologists and other behavioral scientists have been able to cope with this problem, their expertise has not been brought to bear on these studies. (IV 25).

It is difficult to draw general conclusions from current empirical work, because it focuses on high-quality, unique environmental services, rather than medium or low-quality services. Moreover, there is some question whether estimates of option values should be incorporated in benefit estimates, in light of their softness and consequent weakening of the validity of total benefit estimates. (IV 26-27).

Changes in property values have been employed to estimate aesthetic benefits of water pollution control. These.changes have been regarded with some suspicion, because it was felt that they reflect a redistribution of wealth; rather than a net addition to national productivity or efficiency benefits. On the other hand, property value changes may reflect an actualized option demand which should be included as an efficiency benefit, because it indicates that buyers seek to insure a continued future supply of environmental services for private use. (IV 27-28).

The use of property value changes to estimate the aesthetic benefits suffers from several limitations. One is the difficulty of avoiding double counting of benefits with those in the recreational category. Moreover, there is a general scarcity of property value data which can be adequately linked to water quality levels. (IV 28).

4. Health and Production Benefits

Improvements in estimating health benefits hinge on a more precise definition of the relationship between water quality and the incidence of waterborne diseases, such as hepatitis, gastroenteritis, salmonellosis, and typhoid. The key problem in quantifying health benefits is how best to deal with uncertain, long-term relationships, such as the presence and effects of carcinogens. Also, determination of the value of human life is complicated by the fact that society may be willing to expand the effective willingness to pay of an individual beyond his future earnings. (IV 16-17).

Production benefits arise from water pollution control, because water is a direct input to many production activities. These activities may be divided to include municipal, industrial, and agricultural water supplies, commercial fishing, and materials damage categories Available estimates of these benefits have been made with the aid of the alternative cost, or technical coefficient approach. This approach is based on estimating the additional cost incurred in these production activities, because of water pollution and assumes that the reduction in such costs would be proportional to the reduction in pollution levels. The- costs addressed include treatment of water before use, maintenance and repair of equipment, and decreased production. (Heintz et al., 1976).

Production benefit estimates obtained under this approach suffer from the failure to consider substitutions and other market adjustments made by the producer to mitigate the effects of pollution on production activities. Another problem lies in the assumption that marginal costs of treating man-made pollutants are equivalent to the prorated portion of the average cost of treating both man-made and natural pollutants. This may lead to over estimation of the benefits due to control of man-made pollution. A problem in the estimation of agricultural damages on the basis of crop prices is due to distortions brought about by price support for farm products and other institutional manipulations. (IV 18-19).

5. Conclusions and Recommendations

The following conclusions are drawn from the preceding discussion:

- The theoretical framework for estimation of water pollution control benefits is far more advanced than the corresponding empirical work (IV 29)
- Estimates of national benefits of consumption losses (e.g., recreation, aesthetics) are much less firm than those for production losses and prospects for improvement of this situation are not good (IV 29)

- Reduction of travel costs offers a potential for assessing recreational benefits at a higher level of aggregation (IV 30-31)

The following actions are recommended to improve estimation of water pollution control benefits:

- Prepare more- complete and valid behavioral response functions, including demand curves for specific recreation sites (II 50; IV 30)
- Establish a long-term "behavioral: monitoring system" that would measure simultaneously basic economic and ecological factors, objective and perceived water quality parameters, recreational activity, and property values (IV 31-32)
- Apply the new models to the estimation of recreational benefits (IV 23-24, Attachments A and B)
- Improve interview techniques for estimating aesthetic benefits by seeking help from behavioral scientists (III 35-36; IV 25)
- Prepare improved damage functions defining the relationship between water quality and the incidence of waterborne diseases (IV 16)
- Prepare improved estimates of the value of human life (II 50; IV 17-18).

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II. BENEFITS OF POLLUTION CONTROL

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A. INTRODUCTION

The issues to be discussed in this paper can be stated most concisely in the form of four questions. First, "would national estimates of benefits from controlling air and water pollution be useful to public officials and others concerned with evaluating pollution control policy alternatives?" Second, "is it possible to use the available economic theory, empirical techniques, and data base to make national estimates which can be supported on logical and scientific grounds?" The third and fourth questions presuppose generally affirmative answers to the first two questions. The third is, "do available estimates of national pollution control benefits adequately reflect the present state of the art?" And finally, "what can be done to produce better estimates of national benefits?"

It is perhaps misleading to present the "possible" and "useful" questions as if they were entirely separable. The way the questions are asked implies the possibility of a simple yes or no answer. But what is "possible" depends upon the resources and effort devoted to the exercise of measurement. And this in turn depends upon the expected usefulness or utility of the information being sought. The importance of the question and the likelihood that more information will improve the decision determine the value of additional information such as estimates of national benefits. Policy makers should seek more information on national benefits as long as the marginal value of the improved benefit measure exceeds the marginal resource cost of obtaining it.

Section B continues the discussion of the possibilities and usefulness of national estimates of benefits in somewhat more detail. While the questions posed at the outset focus primarily on national estimates of benefits, it is not possible to provide complete answers without some reference to the problems and possibilities for estimating benefits for individual pollution control projects, river basins, and air sheds. Generally, national estimates of benefits involve some form of extrapolation or aggregation based on parameters and relationships derived from more narrowly focused studies of a particular region or pollution control project. Of necessity then, the evaluation of the possibility of national estimates must consider the theory and practice of benefit estimation in general. This is the topic of Section C.

Secion D discusses three conceptual problems in benefit estimation. The representation of uncertainty through the use of probabilistic statements and confidence intervals is recommended. The willingness to pay versus forgone earning approaches for valuing human life are discussed. The latter seems to be unsatisfactory on both conceptual and empirical grounds. In the absence of definitive estimates of willingness to pay, it is suggested that decision makers experiment with explicit assumptions or value judgments about the value of life. The problem of temporal aggregation of benefit streams over time is discussed in terms of the principle of discounting and present value. The problem of intergenerational effects seems to raise questions which are probably fundamentally ethical in nature.

Section E reviews a number of problems in the empirical techniques and data for benefit estimation. Topics covered include overlap and gaps among categories, the effect of multi-collinearity on measurement and prediction, the biases due to misspecification of variables, and the problem of adequately summarizing air pollution data collected over a substantial interval of time. The section concludes with a review of the adequacy of available data and technique for dealing with air pollution data, property value effects, health effects of air pollution, recreation benefits, and benefits from increased industrial productivity and reduced vegetation and materials damages.

Section F discusses the process of developing national estimates of benefits from the building blocks of region-specific, pollutant-specific, and effect-specific studies. Specific suggestions are made for estimating national mortality changes from cross-section regressions of mortality versus air pollution and aggregating the information contained in property value studies for individual cities. Also the problem of national recreation benefit estimation is discussed.

Section G makes a number of specific recommendations for improving estimation techniques and for additional research. The final section is devoted to some concluding observations.

B. POSSIBILITY AND USEFULNESS OF NATIONAL BENEFIT ESTIMATES

The feasibility, or possibility, and usefulness of national benefit estimates are the cardinal issues in this critical assessment. They are examined here along with the corollary issue of information content.

1. On Possibility

Since the nation is simply the aggregation of its regions, however defined (as air sheds, river basins, or political subdivisions), the possibility of developing national benefit estimates hinges on our ability to make estimates of particular classes of benefits in a specific region. Data from particular regions constitute the building blocks of national estimates. If nothing meaningful can be said about the benefits of a specific pollution control plan in a particular region, then no meaningful aggregation to the national level is possible.

Estimating benefits is essentially an economic process. The discipline of economics is the source of the concept of benefits; and the definition of benefits and the conceptual basis of their measurement are derived from a type of economic model. Yet benefit estimates must be built upon a non-economic base. For example, health benefits due to air pollution control must be built upon scientific knowledge of the relationship between pollutant concentrations and human health. In recreation and fisheries, benefits stemming from water pollution control may require knowledge of the relationship between pollutant levels and biological productivity. It is clear that lack of information in some non-economic areas severely limits our ability to make estimates of economic benefits. But aside from acknowledging the existence of this problem, no more will be said here. Rather our attention will be devoted to the economic aspects of benefit estimation.

Suppose the Administrator of EPA wished to know the magnitude of the benefits to be expected from a particular pollution control program. If asked, could the economist specify what economic theory and models he would use, what data he would like to have, and what empirical techniques he would apply to the data to obtain benefit estimates? The answer is a qualified "yes". After completing a review of the available techniques for measuring the benefits of water pollution control for the U.S. Environmental Protection Agency, I concluded: "The economic theory and analytical techniques for evaluating benefits for most types of uses are relatively well developed. At least, this is the case for the most significant classes of user benefits (Freeman, 1975)."

The qualifications are threefold. First, some of 'the data the economist would like to have is non-economic, e.g. dose-response functions, physical damage functions, and these data may not be available. Second, in the economic realm there are still major unresolved theoretical and empirical issues with respect to valuing human life and health effects and various forms of non-user benefits such as aesthetics and option value. And third, the kind of economic data that the economist would like to have are seldom already available or easily obtainable at modest cost. Major data gathering efforts would be required to obtain the primary economic data called for by the correct theoretical models. Lacking data in the ideal form, the economist must resort to second best theoretical constructs and utilize sophisticated econometric techniques in an attempt to wrest some modicum of useful information from the limited and imperfect body of data.

Because of the several qualifications, successful benefit estimation, either at the local or national level, requires striking a balance between rigorous theory and correct empirical technique on the one hand and pragmatism and informed judgment on the other. Where there are gaps in knowledge concerning key parameters and relationships, and where it is not possible to devote resources to closing these gaps within the scope of the existing research effort, it may be appropriate to make an informed assumption about the unknown relationship in order to push the analysis through to its conclusion.

This procedure is valid provided that: the assumption is made explicitly and openly; the basis for choosing the assumed value rather than some alternative is fully discussed; and the implications of alternative assumptions are made clear through sensitivity analysis on the outcome or carrying confidence limits through to the final outcome. The necessity for making assumptions may stem from ignorance concerning empirical relationships, e.g., dose-response relationships for air pollutants, or inherent problems of evaluation, e.g., the valuation of human life: These issues are discussed in more detail in a recent National Academy of Sciences Report to U.S. EPA (National Academy of Sciences, July 1975, esp. Chapter 6, and Appendix 8).

If the practice of benefit estimation were highly developed, the estimation of benefits at the national level would proceed simply by estimating benefits separately for each region or basin, and then summing them over the nation as a whole. But this is clearly not the case. The real question for policy analysts is how far can one depart from the ideal of rigorous and theoretically precise estimation for all sites, moving toward the bastardized but pragmatic process of first approximation, reasonable assumption, and judgment, and still obtain estimates which are considered reasonable and useful for the questions at hand. It is hard to provide an answer to this question in the abstract. As was indicated in the introduction, this depends in part on the resources available to support adequate investigation, and in part on the kinds of policy questions being posed and the value of additional information.

2. On Usefulness

Useful to whom? To officials responsible for environmental policy planning and decision making. Benefit estimates are useful if they provide an improved information base for environmental decision making. Achieving air and water pollution control objectives established by Congress will involve massive expenditures both through the public sector and private sectors. There is a potential for substantial gains through more effective utilization of the resources devoted to pollution control via the judicious use of benefit-cost analysis in evaluating policy alternatives. It must be emphasized that benefit-cost analysis as we use the term is not a rule for decision making. Environmental decision makers may have other objectives besides the simple economic efficiency objective which underlies the benefit-cost rule. For example decision makers may be concerned with equity considerations, intergenerational effects, or risk aversion, none of which can be incorporated in a simple equation for decision. making purposes. Also, it is seldom feasible to provide the full range of complete and accurate benefit and cost information to the decision maker which would be required for the unqualified acceptance of the benefit cost rule. Rather, questions of uncertainty and information gaps are likely to exist.

Benefit-cost analysis can be very valuable as a framework and a set of procedures to help organize available information. In this way, benefit cost analysis does not dictate choices, nor does it replace the ultimate authority and responsibility of decision makers. Rather, it is a tool for organizing and expressing certain kinds of information on the range of alternative courses of action. It is in the context of this framework for arraying information that the usefulness of national benefit estimates must be assessed.

Although the major thrust of Federal pollution control policies has already been established by the U.S. Congress, there are still many important decisions to be made. Also, looming problems may force reconsideration of major elements of existing policies. Most of these issues involve either an implicit or explicit weighing of benefits versus costs. For example, U.S. EPA and U.S. Congress are weighing proposals to change the emissions standards and/or the timetable for compliance for automobiles. National Secondary Air Quality Standards require at least an implicit balancing of benefits versus costs. And to defend effluents standards based upon the best practical treatment and best available treatment criteria against legal challenge, U.S. EPA will have to have information on the benefits to be expected from the standards they are setting. There are two things to note from this sampling of future U.S. EPA and Congressional decision problems. First, while decision makers may have other objectives besides economic efficiency, it is clear that economic considerations, broadly defined, will play a significant role in the decision making process. And second, each of these decision problems is national in scope and requires national estimates of benefits and costs.

This discussion has established the potential value of national estimates of benefits. But it must be recognized that, under some circumstances, benefit estimates can be damaging rather than useful. If estimates succumb to the fault of misplaced concreteness, if they contain conceptual or analytical errors, if they do not make explicit the key assumptions and value judgments involved, and of they do not express their inherent lack of accuracy through some device such as confidence limits, the estimates may do more harm than good. They may mislead policy makers in key decisions. And as their faults and weaknesses become known, they may discredit the whole process of benefit estimation and policy analysis.

Finally, even if benefit information does not become an input into a decision process, the exercise in quantification and measurement that benefit estimates require may be itself of educational value to researchers and policy makers. The exercise requires that investigators gain a better understanding of the nature of different pollutants, the paths that pollutants follow in reaching people, and the variety of ways in which pollutants affect the uses that people make of their air and water environments. Even if the exercise does not bear fruit in the form of monetary estimates of benefits, the insights gained and the pieces of information developed may be of value themselves.

3. Information Content

A major factor influencing the usefulness of estimates of national benefits is the nature and quantity of specific information contained in the estimates. A statement that "air pollution costs $20 billion per year" contains almost no useful information. To be useful for policy purposes, any statement about national benefits must abide by the following minimum provisions:

- Consistent terminology
- Well defined pollutant levels
- Identity of pollutants
- Sources of pollutants.

The statement must be consistent in its use of the terms "benefit," "cost," and "damage". The benefits of pollution control are measured by comparing the present situation characterized by a known degree of pollution with some specified hypothetical alternative for which pollution has been reduced or eliminated. Benefits are the gain associated with reduced pollution. The statement of benefits should make clear whether the measure refers to <u>total</u> benefits for some non-marginal change in pollution levels or <u>marginal</u> benefits for some small change in pollutant levels. The statement should also indicate whether benefits are defined <u>per capita</u> or in the aggregate.

Damages represent the mirror image of benefits measuring what is lost in moving from some hypothetical clean state to the existing level of pollution. Pollution control benefits are the same as reduced damages. The term "costs" should be used only to refer to resources absorbed in the process of controlling or reducing pollution. Its use to denote damages should be avoided.

The statement concerning benefits must clearly specify the alternative pollution levels being compared, both the present dirty level and the hypothetical cleaner alternative. Is the polluted state defined as conditions in 1975, or for example, 1973 (when pollutant levels and adverse effects may have been either higher or lower)? Specifying the reference year is also important for determining the price level for expressing dollar measures of benefits (e.g., in 1973 dollars), and for specifying values for other socioeconomic variables which might influence the analysis of benefits.

Four choices for the hypothetical alternative seem to present themselves:

- Zero ambient concentrations of pollutants (this may be unrealistic where there are natural sources of the pollutant in question)
- Zero manmade emissions -- that is, ambient levels equal to background levels from natural sources
- Ambient levels above background levels but below all known thresholds (this alternative would be difficult to implement, because of the considerable controversy over threshold levels)
- Ambient levels at promulgated air or water quality standards (this is the most useful alternative for evaluating present pollution control policies).

The estimates should make clear which pollutant or group of pollutants is being referred to. Where the benefit estimates are provided for a group of pollutants (e.g., all air pollutants), the statement should include a disaggregation or breakdown by individual pollutants, unless the pollutants within the group act synergistically, so that such a separation of effects is not analytically possible. Benefit estimates for a group of pollutants may also be useful where the group is controlled jointly.

For each benefit estimate,the statement should indicate whether all sources are included, or, for example, only mobile sources. Where the purpose of the benefit estimate is to evaluate a pollution control policy, benefit estimates should exclude potential benefits associated with non-controlled sources. For example, pollution control benefits associated with the control of non-point water pollution sources should not be included in an estimate of benefits associated with municipal and industrial point-source control program.

The kind of information which should be contained in a statement of benefits also depends upon the nature of the policy question for which the estimate was made. For example, in the early stages of the development of a pollution control policy, the most important question might be one of priorities, i.e., which classes of pollutants should be controlled most quickly. For this purpose, very rough order-of-magnitude estimates of total benefits by pollutant would be very helpful. Later, as control plans are developed, marginal benefits, and 'benefits by source would be required.

The main thrust of Federal policy since 1970 has been away from regionally differentiated air and water quality standards and toward uniform national ambient standards and national standards for emission levels and control technologies. This evolution of a nationally standardized set of policies has increased the importance of national estimates of benefits. The process of setting national primary air quality standards would be aided by national estimates of marginal benefits by pollutant. And the development of pollution control strategies requires national estimates of benefits by source.

In conclusion, the type of policy question being considered governs the nature and detail of the benefit information required. Planning on a regional basis requires estimates of regional benefits and costs. National policy choices require national estimates. And since the building blocks of valid national estimates of benefits are regional studies of specific pollutants, once these studies are done, their aggregation to the national level is relatively simple. And the effort to get better national estimates will stimulate research on obtaining better building blocks.

C. THE THEORY OF BENEFITS

This section reviews the conceptual basis of benefits and some empirical techniques for estimating benefits. These topics have been treated extensively in other studies for the U.S. EPA (Haveman and Weisbrod, 1975; Freeman, 1975).

1. Efficiency and Equity

By definition, benefits are desirable consequences. But we require some criterion for defining and measuring desirability. Welfare economics has conventionally distinguished between efficiency and equity as criteria for judging alternative economic states. Efficiency refers to the total availability of those goods and services valued by individuals without reference to whom they accrue. Equity refers to the pattern of the distribution of available goods and services among individuals. What constitutes equity or fairness in the distribution of goods and services cannot be defined objectively. Equity involves value judgments about the relative "deservingness" of individuals. For this reason, economic analysis focuses on the efficiency criterion on the argument that it is objective or value-free.

The efficiency criterion requires a rule for assigning values or prices to goods and services so that they can be added up to determine a total value. The price system of a market economy provides the necessary set of relative values, provided markets are competitive, there are not externalities, etc. These prices would appear to constitute the set of values necessary for the implementation of an objective efficiency criterion, and to validate the dichotomy between efficiency and equity. But this is not the case. And this is one of the insoluble problems in the analysis of benefits. The price set is not independent of the initial distribution of wealth among individuals in the economy. Thus, if the price set is taken to be valid as a measure of values, this implies that the underlying distribution of wealth which produced those values is acceptable in equity terms. A redistribution of wealth will lead to a different set of relative prices. And an allocation of resources judged efficient under the initial distribution would likely be inefficient under the new distribution. Which measure of efficiency is to be preferred depends upon one's value judgment about the equity of the two wealth distributions. There is no way around this problem, so it is typically ignored in the practical business of applied welfare analysis. In other words, the existing- distribution. of wealth and its resulting set of relative prices are assumed to be acceptable in equity terms.

2. Measurement of Benefits

Benefits are defined in terms of the increase in welfare or utility of consumers stemming from some action to control pollution. Benefits can accrue to consumers either directly in the form of increases in the availability of utility conveying goods and services (e.g., improved health, better visibility, improved recreation opportunities), or indirectly through increases in production efficiency (for example, due to reduced defensive expenditures, reduced materials damages, etc.). Pollution control involves the use of limited resources which have opportunity costs measured in dollars. This means that the benefits must also be defined and measured in commensurate dollar terms. Furthermore these dollar measures must be firmly rooted in and based upon individual preferences and values.

Economic theory shows that there are two ways in which monetary measures of welfare changes can be derived from individuals' preferences. The two approaches differ only in their definition of the *status quo ante* from which the welfare change is measured. One approach, termed the willingness-to-pay approach, asks how much an individual would be willing to pay to receive an extra quantity of the utility-conveying good or service, rather than do without. It assumes that the individual does not have a legal property right in additional units of the good, and therefore must give up control over other goods and services (pay) in order to receive more of this good. The other approach, termed the compensation approach, asks how much the individual would have to be compensated in money terms in order to induce him to give up or forego some quantity of the good. This approach assumes that the individual has a legal property right in the good, and could only be induced to give up the good if the amount of the compensation conveyed an equivalent amount of utility. (National Academy of Sciences, 1974, pp. 400-404).

The two approaches lead to quantitatively different answers only if the marginal utility of income to the individual changes as the individual moves from one position to another. If the marginal utility of income is diminishing, the compensation approach will lead to a higher measure of benefits than the willingness-to-pay approach. Where the marginal utility of income is constant, or can be assumed to be approximately constant (for example, where the changes are very small relative to total income), the two approaches can be taken to be equivalent.

The benefit associated with a particular pollution control action is defined as the sum of the willingness-to-pay of all individuals affected directly or indirectly by that action. Analytically, willingness-to-pay implies the existence of a demand curve for the consequences of that action. Benefits are equal to the area under that demand curve, properly defined. Benefit estimation involves an attempt, either indirectly or directly, to determine the shape of that demand curve. This definition of benefits meets two important criteria for an adequate framework for benefit estimation: the definition is firmly rooted in the economic theory of individual preferences and values and it leads to objectively determined monetary measures of welfare or benefit.

3. The Estimation Process

Although the definition of benefits focuses on the existence of a demand curve, its application in the realm of pollution control must also deal with two other problems associated with the "production" of benefits. The process of producing pollution control benefits has three distinct stages:

- Improvement in environmental quality through reduction of pollutant discharges
- Increase in uses of environmental amenities due to their improved quality
- Increase in willingness to pay due to changes in use of environmental amenities.

A reduction in the quantities of polluting substances being discharged into the air or water leads to an improvement in various measures of air or water quality. Modeling this transformation process between changes in residual flows and changes in ambient pollutant levels is outside of the realm of economics. Yet it is a task which must be done before the benefits of pollution control projects can be estimated.

Changes in ambient pollutant levels lead to changes in the ways in which individuals make use of the air or water, that is, changes in the level and composition of the stream of environmental services yielded by the air and water bodies. For example, changes in ambient air pollutant levels may lead to changes in morbidity and mortality rates. Understanding these relationships is an essential part of the estimation process. This might be termed the <u>measurement</u> process to distinguish it from the process of <u>valuation</u> which constitutes the next stage.

Changes in uses or service flows have their counterpart in changes in aggregate willingness to pay for uses of the environment. Determining the relationship between changes in quality and changes in use is only a partly economic problem. Determining the relationship between use and value is strictly the economist's domain, since here the economic concepts of demand and value are central to the analysis.

The benefit associated with a change in air or water quality has been defined as equal to the area under the demand curve for the environmental service over the relevant range. But, since environmental services are generally not bought and sold in organized markets, there may not be any direct way of estimating the shape of this demand curve by applying normal econometric techniques to observed market data. The basic methodology used for estimating benefits involves techniques for inferring values of environmental services where market processes have failed to reveal these values directly. Thus, benefit estimation often involves a kind of detective work for piecing together the clues about the values individuals place on these goods as they respond to other economic signals.

There are several different situations where the way in which environmental services enter economic processes permits estimation of willingness to pay for improvements in environmental quality by indirect means. In an earlier study for the U.S. EPA (Freeman, 1975), I analyzed the economic theory underlying several types of cases, where environmental services were inputs in production, where environmental services were complementary to other goods and consumption, where environmental services were perfect substitutes for other goods in consumption, and where environmental quality levels were characteristics of fixed assets such as land. In that study, I also reviewed a number of techniques, e.g., market demand analysis, net productivity, net factor income, Clawson-Knetsch travel costs studies, land value studies, and interview techniques, in light of the earlier discussion of economic theory. Each of these techniques (except the interview technique) relies on some model of individual behavior and some set of assumptions about the nature of the benefits being analyzed to deduce a relationship between the unobserved values individuals assign to environmental benefits and related observable market signals.

D. CONCEPTUAL PROBLEMS IN BENEFIT ESTIMATION

There are a number of conceptual issues that need to be addressed in the process of benefit estimation. Among the most pressing of these are valuation of human life, handling of overlaps and gaps, aggregation of the stream of benefits over time, and expressing uncertainty of the results.

1. Valuation of Life

A major category of potential air pollution control benefits is improved health and reduced mortality. Assuming that these benefits can be measured or quantified, how can monetary values be attached to them? Some might say that putting a price on human life is insensitive, crass, and even inhuman. But this point of view must be rejected on practical grounds because both individuals in their day to day actions and governments in their decisions about social policy do in fact make tradeoffs between changes in probability of death and other goods with money values; and these tradeoffs imply money price tags being attached to life.

Individuals in a variety of actions act as if their preference functions included probability of death or life expectancy. They make decisions which involve reductions in life expectancy in return for increases in income or other goods and services, revealing, thereby, that they perceive themselves to be better off having made these choices. Individuals who continue to smoke despite the Surgeon General's warnings could be viewed as trading off the consumer surplus attached to smoking against the now widely publicized reduction in life expectancy. Individuals also make implicit tradeoffs between life expectancy and reduced travel time when they chose a mode of travel, for example private autos vs. bus. The individual willingness to pay framework has been developed by Schelling (1965), Mishan (1971), Zeckhauser (1974), and Thaler and Rosen (1975). Thaler and Rosen in particular have developed a framework for estimating the individual tradeoff between probability of death and higher wages in more risky occupations; and they have tentatively estimated the implied value of human life to be between $176,000 and $260,000 per life. Although this estimate cannot be taken as definitive, it does provide a point of reference for further work in the area and for assumptions and value judgments as described below. (National Academy of Sciences, 1975, Chapter 6).

What should be the basis for determining these values? The conceptually correct basis for valuation is individual willingness to pay. But this willingness to pay must be defined and evaluated in the correct context. The question is not how much would one be willing to pay to avoid certain death tomorrow. Rather, for the relevant policy questions, e.g., health effects of pollution control, safety and accident prevention, the precise identity of the people affected is not known. Safety regulations reduce the probability that any one individual in a population at risk will be killed during a given period of time. It is this kind of question that Thaler and Rosen investigated. Reductions in air pollution, for example, are likely to affect the whole probability distribution of the date of death for affected individuals. One measure of this change in the probability distribution would be to define the change in life expectancy. The changes in higher moments of the probability distribution might also be important, especially for things such as accident prevention. (Freeman, 1975).

The other major approach to valuation in the literature is the so-called productivity or human capital approach. It values each life lost at the present value of the expected stream of future earnings for that individual had that individual's death been avoided. There are several serious weaknesses and limitations to this approach. First, it assumes that it is possible to identify _ex ante_ those whose lives will be saved. Second, it does not take into account the probabilistic nature of death and death avoidance in the health and safety problems. Third, there is no logical connection between earnings and willingness to pay, especially in the probabilistic framework. And finally, this measure places no value on the lives of those who are not working for reasons of age, sex, or other factors.

While lost earnings can be readily calculated, that approach is conceptually unsatisfactory. In contrast, the conceptually valid willingness to pay for changes in life expectancy approach is appealing, but it is only now being elaborated and subjected to empirical testing. In the absence of generally accepted empirical estimates of individual willingness to pay, it is still useful for the researcher to proceed beyond the measurement stage in benefit estimation by applying assumed unit values to predicted changes in mortality and morbidity. In this way, the analyst can examine the implications of alternative unit values for aggregate benefit estimates, and for benefit cost comparisons. (National Academy of Sciences, 1974).

However, if such assumptions are made, several points must be kept in mind. First, the assumptions should be made openly and explicitly. This is not the case with estimates of air pollution health benefits provided by Lave and Seskin (1970) who fail to explain the implications of their assumptions about health values. They used earlier data from Dorothy Rice on direct and indirect costs of mortality and morbidity. The indirect cost of mortality was defined as forgone earnings due to early death.

Second, researchers should provide an examination of the sensitivity of final benefit estimates to changes in assumed unit values. For example, final figures could be presented in the format of high and low range and "best estimate". A third consideration is that, whatever assumptions are made about unit values, it would be helpful for readers of these studies to have the assumptions related to other work. For example, if a researcher chose to use a value substantially below that used in other work which might be familiar to the reader, the researcher should offer some reason for making that assumption. Finally, where assumed values are used in making resource allocation decisions, such as allocating medical services, or setting standards for air pollution or toxic chemicals, there is much to be said for using a consistent set of values across the whole range of public decisions.

While this discussion has been carried out in the context of valuing human life, most of the same points can be made concerning assumed unit values for other difficult to price environmental services, for example recreation user days. The Water Resources Council guidelines call for agencies to apply unit values to predicted recreation days in calculating benefits of water resource development. While there are problems in the application of particular unit values (Freeman, 1975), there can be no objection to the practice in principle, provided that the considerations outlined above are recognized. Assumed unit values can be utilized provided they are based upon a review of other analytical and empirical studies designed to measure unit values of recreation under similar circumstances.

2. Overlaps and Gaps

One major problem area in estimating benefits is the possibility of either overlap among or gaps between categories of benefits as estimated by presently used techniques. This kind of problem can arise where two kinds of effects associated with the same pollutant are estimated separately. For example, do estimates of health effects and property value changes associated with particulates involve some double counting of particulate damages or are there additional effects not captured by either measure? Although definitive answers to this question cannot be given here, the discussion will show that it should be possible to determine when such gaps and overlaps exist. It should also be possible to make some judgment as to the significance and likely direction of any biases in the estimated total benefit figures. And this should be useful in deriving confidence limits or high and low bounds surrounding best estimates of total benefits.

Consider the case of air pollution where health benefits are measured by mortality rate studies and aesthetic benefits are measured through property value differentials. The justification for measuring two classes of benefits separately and adding them to obtain aggregate national benefits is that only those effects of air pollution which are perceived by individuals can influence property values, and that people have for the most part been ignorant of the effects of air pollution on their health and life expectancy.

But one can feel somewhat uneasy about this simple resolution of the problem. Some kinds of short term health problems (eye irritation, shortness of breath) may be directly perceived as being caused by air pollution. And there has been a substantial increase in the information (and misinformation) available to the general public about long term health effects and relative air pollution levels around urban areas. Thus, perceptions of health effects may be influencing property value differentials and leading to the possibility of double counting. To gain a better understanding of the problem, it is necessary to consider in more detail exactly what.is captured by each of the two approaches to measurement.

It will be helpful to develop a system of classification for different types of effects. Aesthetic effects are defined to include odor and taste, reduced visibility, soiling, damage to external paints, etc. By definition, aesthetic effects are perceived by individuals. Impacts on health constitute the other broad class of effects. For purposes of this discussion, we need not distinguish between morbidity and mortality effects. But we can, at the conceptual level, distinguish between those health effects which are perceived by individuals and those of which they are ignorant. The former are likely to be primarily clinical manifestations of short term exposures at relatively high levels. Finally, it is necessary to distinguish between those effects which are caused by pollution exposure at home and those which are caused by the person's exposure as he travels around the urban air shed, to work, for shopping, for recreation, etc. These "away from home" effects are independent of the individual's place of residence.

This classification scheme is displayed schematically in Figure II-1. There are six subsets of effects classified by aesthetics, health--perceived, health--unperceived, and in all cases further divided between home and away. Property value studies can only capture those effects associated with the home which are perceived. Health benefits derived from mortality and morbidity studies capture both. home and away effects and both perceived and unperceived health effects.

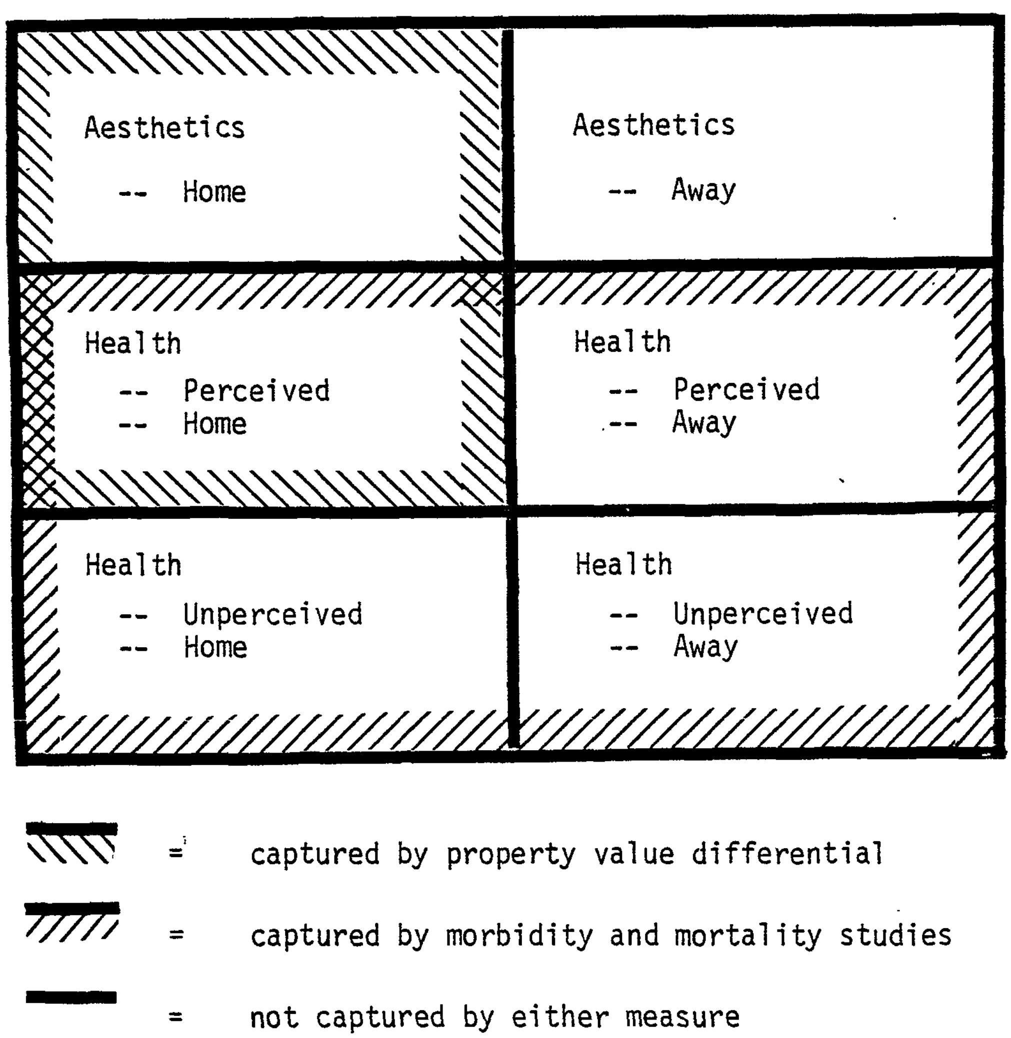

Figure II-1. Classification Scheme for Capture of Effects

The figure illustrates both an overlap and a gap. Perceived health effects at home are captured by both the property value and health effects approaches. But aesthetics associated with away from home exposures are not captured by either measure. Whether the addition of property value and health effect benefits results in an overestimate or an underestimate depends upon the relative size of the doublecounted and omitted categories; Nothing can be said about this question on _a priori_ grounds.

There is a similar kind of problem in the case of water pollution where recreation benefits and property value benefits are both being estimated. Property value measures capture both the value of easy access to the improved water based recreation opportunities and other non-recreation aesthetic benefits (e.g., wildlife appreciation, elimination of odor and unsightly flotsam). In estimating recreation benefits the double counting problem can be avoided by identifying recreation participants as either from abutting property or from away, and counting for benefit purposes only anticipation by those from away. This can easily be accomplished if benefits are being estimated for a particular site, for example by the Clawson-Knetsch method. However, if benefits are being estimated at the national level from a national recreation participation survey, it may not be possible to identify that part of participation attributable to property owners using abutting water bodies. Thus, adding property value benefits to those estimated from a national participation model will involve some degree of double counting.

3. Temporal Aggregation

For many pollution control programs, benefits accrue over many years. We have discussed benefits under the assumption that an estimate is for a given year. But for some circumstances, we may wish to examine the whole time stream of benefits. This would be the case, for example, if the pollution control program involved capital costs now to produce a stream of benefits over the future. Each year's benefit is temporally distinct and not comparable or additive to benefits accruing in other years or with costs without some system of weights. The appropriate weighting system is derived from the discount rate.

There are two issues: the choice of a discount rate and the time. horizon. I see no reason to depart from the accepted practices of project analysis on either of these issues, at least for benefits and costs accruing over the next, say, fifty years. (Kneese and Herfindahl, 1974).

The issues are more complex when we consider effects extending over very long periods of time, for example between generations. Discounting with the normal discount rate can reduce even catastrophic distant future effects to nominal present values. For example, with a relatively low discount rate of 5%, the benefit of avoiding some number of deaths 200 years in the future is reduced by a factor of 0.0006. On the basis of conventional discounting, the benefits of preventing some future catastrophe, for example the effects of possible destruction of the ozone layer, may seem less than the present costs of preventing the effect. It appears that in cases of this sort, the major consideration is not intertemporal efficiency in resource allocation, but rather intergenerational equity in the distribution of welfare. Hence, it should not be surprising that decision rules based on the efficiency criterion should appear to give unreasonable results. This is a problem which is beginning to receive attention in the literature. But as yet, there are no generally accepted answers.

4. Uncertainty of Results

A major problem area is the development of a framework and a language for conveying the uncertainty about the accuracy of benefit estimates. Even the most careful estimate of benefits contains inaccuracies because of errors in the measurement of variables and errors in the statistical estimation of relationships. In addition, it may be necessary for the analyst to make assumptions regarding unknown parameters, relationships, and values. The uncertainty inherent in these errors must be expressed somehow in the final benefit figure. The most appealing way of dealing with these problems is through the use of probabilities to quantify uncertainties. This is straightforward in theory because probability is a natural language for describing uncertain situations. (National Academy of Sciences, 1974, Appendix 8).

Most people are accustomed to using probability informally as a language for describing uncertainty. Weather forecasts are stated in terms of probability of rain. And expectations concerning elections and sporting events are often expressed in terms of odds or probabilities. The same concepts may be used to describe uncertainties related to benefit estimates. Probability theory provides an unambiguous and logically consistent language to reason about uncertainty. In fact, a forceful argument can be made that any logical process for reasoning about uncertainty is equivalent to probability theory.

The same people who use probability naturally in informal situations may be extremely reluctant to use the same ideas in important decision situations. To some extent the problem is one of measurement. Many people are accustomed to viewing probabilities as exact numbers based on objective evidence, for example, as deduced from physical symmetry or observed frequencies from large number experiments. They are uncomfortable with the idea of using subjective probabilities as a language for expressing their judgment on a matter where the available information is limited.

Consider the air pollution/human health relationship. If we had a large body of statistical data on the incidence of mortality over a range of known air pollution exposures, it would be relatively straightforward to assign a probability to a given individual's dying as the result of exposure to that air pollutant. But, if estimates of benefits are desired before this type of data is available, or if those data are very difficult to obtain because of cost, measurement problems, etc., then the analyst must resort to informed judgment and logical reasoning. Judgment must be extrapolated from other information, for example, animal tests, or a review of several less than perfectly successful attempts to measure the desired relationship.

Once the basic assumption has been accepted that probability assignments are not "objective" but represent judgments, that they can summarize information or a state of mind, rather than being physically measurable, then the probability theory for expressing these judgments in a consistent manner is relatively straightforward. For example, what is frequently called the "best guess estimate" can be interpreted as an expected value or mean of the subjective probability distribution. High and low values should be expressed in terms of confidence limits. Where the final estimate is derived from several variables, each with their own estimated degrees of error or uncertainty, the uncertainty surrounding the final estimate is a compound of the component uncertainties. And probability theory provides a logical framework for determining the overall degree of uncertainty.

To those who might argue that the assignment of probability should be rejected because it is subjective, the response is that the present approach to determining best guesses and high and low bounds is also subjective. And often, the method of deriving best guesses and high and low bounds from the underlying data are not consistent from one part of the study to the next. Probability is a language for dealing with subjective estimates in a consistent and logical manner; and, it is one which can be interpreted consistently by others.

E. TECHNICAL PROBLEMS IN BENEFIT ESTIMATION

In addition to the conceptual issues discussed in the preceding section, there are a number of more technical problems that need to be resolved. These include pollution measures, exposure measures, and multicollinearity.

1. Measures of Pollution

A major problem in estimating benefits due to air pollution arises because of systematic errors in the use of aggregate or average measures of the air pollution variable. Consider, for example, the cross section mortality studies of Lave and Seskin which use SMSA's as the sample unit. Assume that there is some single valued measure of the air pollution exposure of an individual. Further, assume that the "true" relationship between this pollution measure and the mortality rate is known. This is portrayed by the solid line in Figure II-2.

Air pollution measures are typically taken at one centrally located monitoring station in the smaller SMSAs, whereas the larger SMSAs may have networks of monitoring stations. In the latter case, pollution measures are some average of readings at the several stations. Assume that for a "dirty" city the air pollution reading at the downtown station is $0\text{-}P_4$. Because some portion of the population lives in suburban areas quite far from the downtown monitoring station, and some portion of the suburban population does not regularly travel to the downtown area, $0\text{-}P_4$ is an overestimate of the true average pollution exposure of this urban population. Assume that the true measure is $0\text{-}P_3$. Reference to the true pollution-mortality relationship shows that this dirty city would have mortality rate of $0\text{-}M_3$. The observed pollution-mortality data would be plotted as point A in Figure II-2.

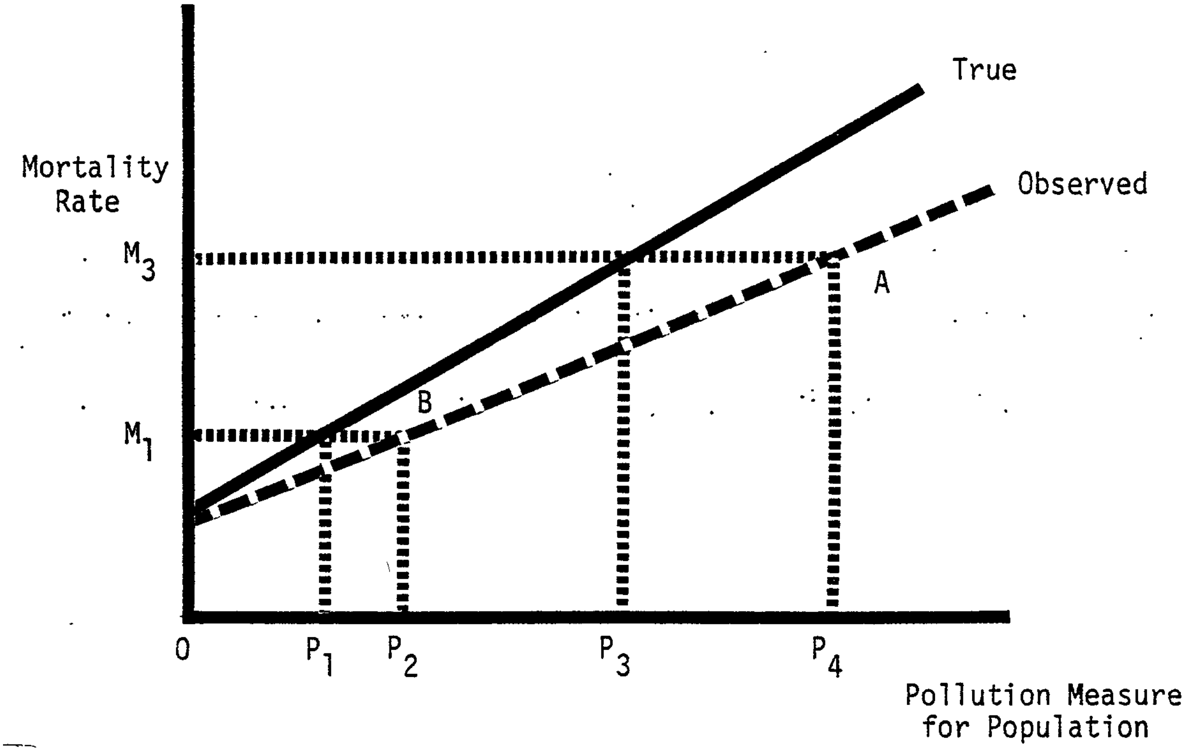

Figure 11-2. True and Observed Relationships Between Pollution Measure and Mortality Rate

In a relatively "clean" city, there will also be a divergence between recorded and actual pollution exposures. However, the divergence will be much smaller, since the difference between the "clean" suburbs and "almost clean" downtown area will be much smaller. If $0\text{-}P_2$ is the recorded pollution measure for the clean city, the clean city observation would be point B in Figure II-2. It can be seen that a regression line fitted to the recorded data would lead to an underestimate of the regression coefficient relating pollution to mortality.

However, while the estimate of the regression coefficient is biased by the error in the pollution measure, if the regression equation is used to predict changes in mortality conditional upon changes in pollution, the regression equation will give "true" predictions. Consider a pollution control program which is expected to reduce recorded pollution in the dirty cities from $0\text{-}P_4$ to $0\text{-}P_2$. The regression equation predicts a reduction in mortality of $0\text{-}M_3$ to $0\text{-}M_1$.

The pollution control program will actually reduce true exposure from $0\text{-}P_3$ to $0\text{-}P_1$. And the true reduction in mortality will be just that predicted by the regression equation.

Similar problems might arise for mortality or morbidity studies based upon a sample of individuals, if the pollution variable is measured by some proxy. For example, suppose each individual's exposure was taken to be a function of pollution levels at his residence. Then, the recorded pollution measure would understate true exposure for those individuals living in the "clean" part of the city and spending some part of the working day in the "dirty" part of the city. Similarly, for those living in the dirtiest part of the city, the recorded pollution measure is likely to overstate true exposure. By a line of reasoning similar to that developed through Figure 11-2, it can be shown that this divergence between recorded and true exposure measures will lead to an underestimate of the slope of the regression line relating exposure to morbidity or mortality. However, unlike the preceding case, the biased regression equation will not provide correct predictions. Rather, the regression equation will underpredict reductions in mortality or morbidity associated with reductions in pollution exposure.

2. Pattern of Exposure

One of the problems in doing research on dose-response relationships or epidemiological studies of the air pollution-mortality relationship is a choice of a time dimension for the air pollution variable. The air pollution level at any particular point in an urban area is an instantaneous variable which fluctuates over time. The true exposure of an individual located at that point is measured by a trace of the time path of that instantaneous variable over the relevant time period. The published data on air pollution levels which are used to generate exposure variables for empirical research involve various approaches to summarizing this instantaneous time path. Inevitably these summaries, such as the annual mean, lose information.

Also, at least in part because of measurement methods, averages are struck over shorter time periods, for example the 24-hour average for particulates, and 8-hour and 1-hour averages for other pollutants. These shorter averages can also provide a basis for summary measures of exposure. For example, Lave and Seskin used the lowest 24-hour average recorded during a year as one measure of long term exposure, No one or two of these measures completely represent the true exposure of any individual. Empirical research is hampered by this inability to accurately characterize exposure over long periods of time.

An alternative approach to summarizing recorded air pollution data may lead to more accurate characterizations of exposure. The suggested approach is based upon the assumption that the instantaneous air pollution reading can be treated as a stochastic variable. For a city with given emissions patterns, meteorological conditions, and location of monitoring stations, the instantaneous air pollution reading can be viewed as being drawn from a probability distribution. That probability distribution has a mean, variance, and other higher order moments. If the probability distribution is stable, its parameters can be estimated on the basis of readings taken over a long period of time. The air pollution of a city could be reported in the published data in terms of these parameters. These parameters in turn could be used to characterize exposure in empirical research.

3. Multicollinearity

When two pollutants are both thought to be related to an "effect" variable such as mortality rate, and when multiple regression techniques are used to estimate the hypothesized relationship, the process of estimation may be complicated by the problems of multicollinearity. Thus, differences in mortality rates and property value differentials have been associated with differences in the levels of both suspended particulates and sulfates.

For example, suppose the hypothesized relationship is as follows:

$$M = a_0 + a_1 P + a_2 S + a_3 Z + e \qquad (1)$$

where M = mortality rate

P = sulfate concentration

Z = an index of other variables-

e = disturbance term

Suppose further that P and S are positively correlated, producing multicollinearity.

It is important to distinguish between problems in estimating the coefficients for equation (1), and problems in using equation (1) for prediction of mortality rates. It can be shown that when equation (1) is estimated with multicollinearity present, the estimates of a_1 and a_2 will be unbiased. However, they are likely to be imprecise in the sense that the estimates will have relatively large standard errors. In fact, it is possible that the equation may have an R^2 well over 0.95, with none of the regression coefficient estimates being significantly different from zero. It is also possible that estimates may have the wrong sign. But it is important to note that, while the individual coefficient estimates may be imprecise, the equation as a whole may still provide good estimates of mortality rates when the independent variables are known.

Now suppose that equation (1) has been estimated and that the estimate of a_2 was insignificant by the ordinary statistical criterion. One might be tempted to drop the sulfate variable and estimate a new equation (2):

$$M = a'_0 + a'_1 P + a'_3 Z + e' \qquad (2)$$

However, this would be incorrect. The estimate of a'_1 will be biased. Given a positive correlation between P and the omitted sulfate variable, it can be shown that $a'_1 > a_1$ This is because the estimate reflects not only the partial relationship between P and M, but also part of the relationship between the omitted variable and M. Similarly, if P were dropped and the equation were estimated with only the S, the estimated coefficient for the S variable would be biased upward.

In summary, when the regression equation is to be used to predict changes in the dependent variables, the correct procedure is to use all variables and all coefficients, including those which are insignificant, to predict changes in the dependent variable. In the case of air pollution health benefits, multicollinearity does not pose insuperable barriers to benefit estimation. However, in the case of the property value approach to air pollution control benefits, the problems are more severe.

This is because benefits are not measured by changes in property values stemming from changes in pollution levels (Freeman, 1974). Rather, the partial relationship between the pollution variable and property values is used to determine a marginal willingness to pay function. Where there is multicollinearity between a pair of independent variables (e.g., two pollution variables, or pollution and distance from central business district), this partial relationship can be estimated only imperfectly or imprecisely. In other words, the standard error of the pollution coefficient will be high. This uncertainty should be reflected in the final benefit figure calculated from the regression equation.

Most of the published property value and mortality studies use only one or, at most, two air pollution variables, for example some measure of particulates and sulfates. But if there are other air pollutants which also affect the property value or mortality (for example, oxidants or nitrogen oxides) and these other pollutants are correlated with the pollution variables included in the 'estimating equation, then the estimates will be biased upward, as was pointed out above. I am not aware of any studies that have attempted to determine the significance of this problem.

Published studies of Lave and Seskin have focused primarily on long-run or chronic effects of exposures to relative low levels of pollutants. They have found that long-term measures, such as annual average and minimum bi-weekly exposures work best in their regression equations. This raises the question of whether benefit estimates based on the Lave-Seskin equations might be missing the contribution to mortality made by, health effects associated with short-term exposure to high levels of pollutants. A consideration of the multicollinearity problem suggests that mortality equations should be estimated with, say, two sulfate variables, one to reflect the presence of short-term high level exposures and other to reflect long-term chronic exposures. These two variables are likely to be correlated and when their coefficients are estimated in the same equation, the standard errors may be high. However, to omit one of the variables on those grounds will lead to biased estimates of the coefficient for the other variable. Since the objective of obtaining estimates of air pollution benefits is best served by obtaining regressions with unbiased estimates and high predictive power, insignificant variables should not be omitted where multicollinearity is present.

F. PREPARING NATIONAL ESTIMATES

The conceptually correct approach to aggregation of benefits at the national level is to examine each region separately, within that region to analyze each pollutant and each effect separately, then to sum benefit measures across all effects, all pollutants, and all regions, to get the national figure. This section reviews the criteria for selection of regional studies and the process of aggregation from these building blocks.

1. Criteria

National estimates of benefits can be judged in terms of two general considerations. The first looks at the underlying benefit study used as a building block. The second general criterion is the logic underlying the extension or aggregation from the building block benefit study to the national level. The following criteria are intended to provide a benchmark against which to evaluate specific benefit studies which are to be used as building blocks.

Since the objective of the exercise is determination of values, a technique should lead to monetary measures of values or benefits. This means, for example, that a measurement technique which predicts the increase in recreation user-days associated with a given reduction in pollution does not meet this criterion. For, although the information is useful, it does not fully meet the needs of water resource planners for benefit measures which are commensurable with their monetary estimates of pollution control costs. Similarly, while studies of the relationship between mortality and air pollution are essential building blocks in the estimation of benefits, they do not determine value. In some cases, the analyst may not have credible estimates of individual values. In these circumstances, he may be justified in making some explicit assumption about unit values, e.g., value per death avoided, and determining the implications of alternative value judgments.

The technique and estimating procedures should be based analytically and empirically on individual behavior and preference. Some measures of the value of reduced mortality have been based upon. the earnings of affected individuals (Lave and Seskin, 1970). Such measures do not meet this criterion, since there is no known relationship between willingness to pay, on the one hand,and earnings, on the other. The most obvious limitation of the lost earnings measure is that it places no value on the lives or health of those who are not working for reasons of age, sex, or other factors.

The measures of use and value should be related to changes in pollution levels. For example, the analysis of the demand for water-based recreation is not adequate, unless the analysis shows how that demand is affected by changes in pollution and the quality of the water bodies being analyzed. Particularly in the realm of water quality, the difficulty of establishing the relationship between quality and use is a major barrier to better estimates of benefits. We do not yet have a clear idea of what indexes of water quality are relevant to recreational uses of the water, and how people will respond to changes in quality parameters. And furthermore, the links between many of the more subtle water quality parameters and discharge rates are not understood.

Benefit estimates should be based upon a correctly specified theoretical model of individual behavior and the relationships among economic units. The logic of the model must be internally consistent and also be consistent with established theory. When observed relationships are measured empirically, without benefit of an underlying theoretical model, researchers may be led to make faulty or erroneous interpretations of the data. An important example is the discovery by early researchers that land value and air pollution levels were inversely related in urban areas, *ceteris paribus.* They then assumed that changes in welfare associated with reduced pollution would be adequately measured by the associated increases in land values. However, subsequent research based upon theoretical models of urban land markets, has shown that this assumption is not true in general. (Freeman, 1974; Lind, 1973; National Academy of Sciences, 1974, Chapter 4).

The actual measures used in the empirical work should correspond to the variables of the theoretical model. For example, a priori reasoning about the relationship between air pollution. exposure and mortality suggests that the time profile of cumulative exposure of an individual is the appropriate independent or causal variable. But most empirical research on the air pollution-mortality relationship has been based upon air pollution measurements taken at a point in time or over a short period, and at a specific geographic location within an urban area. Thus, the empirical measure of air pollution is not perfectly correlated with the measure called for by the correctly specified theoretical model. The correct theoretical measure may not be available, but the analyst must be sensitive to the problems that might be caused by the lack of correspondence between the theoretically correct variable and the one actually used.

Benefit studies should use the empirical techniques appropriate to the theoretical model and the data at hand. Empirical techniques should be able to cope with such problems as multicollinearity, simultaneity, and identification problems. Empirical techniques which do not adequately control for other variables should be used with great caution. Researchers should be sensitive to the problems caused by misspecification of the variables used and of the functional forms estimated.

No benefit study yet done is completely satisfactory in terms of all six of these criteria. Yet, the researcher and analyst need to push on and do the best they can with available data and analytical techniques using these criteria as benchmarks. Part of the art of benefit analysis involves a sensitivity to the gap between the ideal and the available and knowing how much confidence to place in the estimates being generated. At some point, the problems become so great and likely margins of error so large that the effort is not producing usable numbers.

2. Aggregation from Building Blocks

A correct approach to estimating national benefits from valid building blocks involves several distinct steps. These are now described in more detail.

The first step is to specify the present levels of pollution in each region or unit of analysis, and to postulate the change in pollution or environmental quality which is to be the subject of analysis. The postulated changes in pollution will be determined by the nature of the policy question to which the national benefit estimate is to be addressed. For example, in the case of air pollution, it might be most useful to postulate the changes in air pollution required to achieve national primary standards throughout the country. In the case of water pollution, one could postulate changes necessary to achieve the water quality standards established under the 1965 law. But an analysis which postulates a 50 percent across the board reduction in air pollution does not shed much light on important policy issues.

The next step is to determine the functional relationship between use of the environmental amenity and environmental quality. Use is likely to be a function not only of quality, but also of socioeconomic and other variables which will differ across regions. For example, differences among regions in industrial composition, or importance of agriculture, may mean that the same changes in environmental quality will have different physical effects in different regions.

The third step is to use the functional relationships described above to predict the changes in use for each region conditional upon its postulated change in environmental quality and its other socioeconomic variables.

The next step is to estimate the functional relationship between uses of the environment and marginal value or willingness to pay. This relationship will also be a function of socioeconomic variables and other factors (such as the availability of substitutes as in the case of recreation).

The fifth step is to calculate the value or monetary benefit measure for each region on the basis of predicted change in use and other factors influencing demand or marginal willingness to pay.

The final step consists of summing the predicted benefits across all regions to obtain the national estimate.

These six steps are offered as a benchmark against which to evaluate the procedures used to generate existing national benefit estimates. I know of no study which has followed faithfully all six steps as outlined here. Most of the studies take a short-cut by generalizing from the results of one or two specific studies to the nation as a whole. Sometimes this is reasonable, where it can be reasonably assumed that the variables involved are constant across regions. In other cases, the generalization may involve significant distortions and inaccuracies. Because of the great variety of cases and types of benefits, it is not possible to state general rules as to when such assumptions are valid.

3. Specific Examples

I will now turn to some specific suggestions for generating national estimates for pollution control benefits in the three quantitatively most significant areas: health benefits from air pollution control, aesthetic benefits from air pollution control (property values), and recreation benefits from water pollution control. I believe that it is possible to develop useful estimates of pollution control benefits in these three areas on the basis of present theory and analytical techniques.

In the areas of health and property value benefits from air pollution control, data bases exist which would permit useful although not definitive benefit estimates. Existing published estimates in these two areas (Waddell, 1974) have used faulty procedures to move from the underlying functional relationships to estimates of benefit and aggregation to the national level. In the case of water-based recreation, the necessary data base does not presently exist. However, work in progress by the National Planning Association under contract to the National Commission on. Water Quality may help to close this gap.

A major component of total air pollution control benefits is accounted for by the property value approach to aesthetics. Most of the property value studies have used data from the decennial censuses. The census collects data from each homeowner respondent on the owner's estimate of market value. It would be highly desirable to improve the data base for property value studies by obtaining value estimates more directly related to market transactions, and by obtaining estimates more frequently than during census years. Crocker (1970) has shown that this is possible and more investigators should follow his lead.

Consider the benefits accruing to households due to improvements in air quality at their residence site. The first step is to analyze the property value-air pollution relationship for a given city using the appropriate regression techniques. The first derivative of the property value function with respect to air quality can be interpreted as a locus of household equilibrium marginal willingnesses to pay. It is necessary to make some assumption about the shape of each household's marginal willingness to pay function through that known equilibrium point. Several alternative assumptions were described by Freeman (1974). Next, for each unit of analysis (household, block, census tract), a change in air quality is postulated and, for each unit of analysis, the area under the assumed marginal willingness-to-pay curve between the original air quality level and the postulated new clean air point is determined by integration. Finally, these are summed across all units to determine the estimate of air pollution control benefits for that city. (Freeman, 1974; National Academy of Sciences, 1974, Chapter 4).

To obtain conceptually correct national estimates, it is necessary to, repeat the estimation of the property. value-air pollution relationship for each city, then repeat the calculations described above. This is because different cities have different levels of average air pollution, different spatial patterns of air pollution, and different vectors of socioeconomic characteristics. (National Academy of Sciences, 1974, Tables 4-7 and 4-8). I have also described a technique based upon the estimation of hedonic price indices for identifying the demand curve for clean air directly. It requires a pooling of air pollution, property value, and socioeconomic data from several cities. (Rosen, 1974; Nelson, 1975). If the demand curve has been properly drawn, it is then possible to integrate areas under these demand curves for all individuals in all urban areas to obtain a conceptually valid estimate of national benefits.

A shortcut approach would be to review the existing air pollution property value relationships and to construct a synthetic (average) relationship which is assumed to apply to all cities. But this would have a higher margin of error than the method described above. Alternatively, one could carry out this procedure for subsets of cities grouped according to some set of characteristics. Then the postulated changes in air quality could be combined with the appropriate assumption about functional form to compute benefits for each unit of analysis within each city. Finally, these could be summed within each city and across all cities to obtain the national benefit figure.

The present state of the art in health effects research can be characterized as follows. Lave and Seskin have produced a substantial body of research showing an association between mortality and air pollution and a number of less comprehensive studies have corroborated this finding. The Lave-Seskin research is based upon cross sectional studies using U.S. SMSA's as the sample unit. At the other end of the spectrum, a substantial number of micro dose-response relationships have been established for specific clinical manifestations. These are primarily related to high acute dosages, at levels not often experienced in urban areas.

The substantial gap between these two bodies of studies must be closed. At the clinical level,, more work should be done to establish the specific mechanisms and cause-effect relationships involved with lower-level, longer-term exposures, such'as those found associated with mortality by Lave and Seskin. On the other hand, epidemiological work should begin to focus on more disaggregated research based upon smaller units of analysis. But this work must await the establishment of a better data base on both mortality and morbidity associated with exposure to pollutants.

I would recommend the following procedure for estimating health benefits from air pollution control. First, existing mortality-air pollution studies are reviewed. Either the single best relationship is selected, or a synthetic relationship is constructed which reflects the range of experience and confidence in different estimates revealed in existing studies. For each unit of analysis defined for the mortality relationships selected (e.g., SMSA, city), a change in air pollution levels is postulated. Then, for each study the change in mortality based upon the change in air pollution and other socioeconomic variables is computed. It should be noted that, if the selected relationship is linear, the predicted change in mortality is independent of other variables. However, if the function is semi-log or log, the vector of other variables must be incorporated in the calculation. Summing the predicting changes in mortality over all SMSA's will give an aggregate measure of deaths avoided for the nation as a whole due to the postulated air pollution control program. To obtain a monetary measure of benefit, it is presently necessary to make some explicit assumption about the value of deaths avoided or postponed. Morbidity effects can be measured and valued in the same manner.

Unfortunately, the most widely quoted estimate of national health benefits associated with air pollution control did not use a correct method for predicting national changes in mortality. After choosing their "best" regression associating total mortality with measures of suspended particulates, sulfate particles, and several socioeconomic variables, Lave and Seskin (1970) calculated elasticity coefficients of the dependent variable with respect to each of the independent variables at the mean values for all variables. Strictly speaking, the elasticity enables one to calculate the percentage change in the dependent variable for a given percentage change in any independent variable.

If the elasticities are constant throughout (i.e., if a log-log regression form had been estimated), then the elasticity coefficients can be used for any magnitude percentage change in an independent variable for any sample point. However, Lave and Seskin estimated a linear form and it is well known that linear functions have different elasticities throughout the range of the function. Therefore, the calculated elasticity coefficient can strictly speaking only be used to estimate changes in mortality for the "average" city for small changes in its population level. A sample calculation suggests that with relatively low elasticities, as in the case cited, the magnitude of the error in using the same elasticity figure throughout for all of the sample points can be substantial. Therefore, the estimated changes in mortality consequent on a reduction in air pollution must be called into question.

Recreation appears to be the largest category of benefits to be realized from water pollution control. There are two major problem areas in the estimation of national recreation benefits. The first is our ignorance of the relationship between water quality and recreation use or participation. Second, it is very difficult to generalize to the nation as a whole from the small number of studies that have been done on the unit value or shadow price to be attached to a unit of recreation (e.g., a recreation day). *A priori* reasoning suggests that the appropriate shadow price depends upon local socioeconomic characteristics, the availability of substitutes, and taste formation mechanisms, such as the "learning by doing" phenomena. Also, many of the recreation sites which have been studied have unique attributes which make it difficult to separate the value of the general. recreation experience from the value attached to those site-specific characteristics.

In estimating the national recreation benefits from water pollution control, there are several points to bear in mind; First, the major barrier to developing adequate estimates of water pollution control benefits is our lack of understanding of the relationship between various measures of water quality, on the one hand, and various recreational uses of water bodies, on the other. The most commonly measured water quality parameters are at best only crude proxies for the more complex vectors of characteristics which influence recreational uses. Second, it is very dangerous to extrapolate predictions of changes in recreation participation or recreation demand from narrowly focused studies of limited geographic areas.

Third, the analysis of recreation benefits must recognize the variety of likely individual responses to changes in the availability of recreation sites. Existing recreationists will increase participation levels; non-participants will become participants; and there will be shifts in the geographic pattern of recreation activity, as recreationists shift from one site to another. Furthermore, there will be both changes in the level and pattern of economic/market transactions associated with recreation, e.g., travel expenditures to recreation sites, and changes in utility levels which have no counterpart in market transactions.

It would be useful to outline briefly the theory of recreation benefits as developed for a single recreation site holding all other relevant economic magnitudes constant. There exists a demand for this recreation site relating quantity demanded of recreation services (e.g., in recreation days) to price.' This can also be interpreted as a marginal willingness to pay curve, relating marginal value to quantity. This demand curve is plotted holding income, prices and availability of substitutes and alternatives, and the quality of this recreation site constant. price is known, as indicated by the line P in Figure 11-3, actual recreation use for quantity demanded can be predicted. Of course, price could be: zero. When the facility is polluted and the demand curve with pollution is as shown, the quantity of recreation days would be $0\text{-}Q_1$.

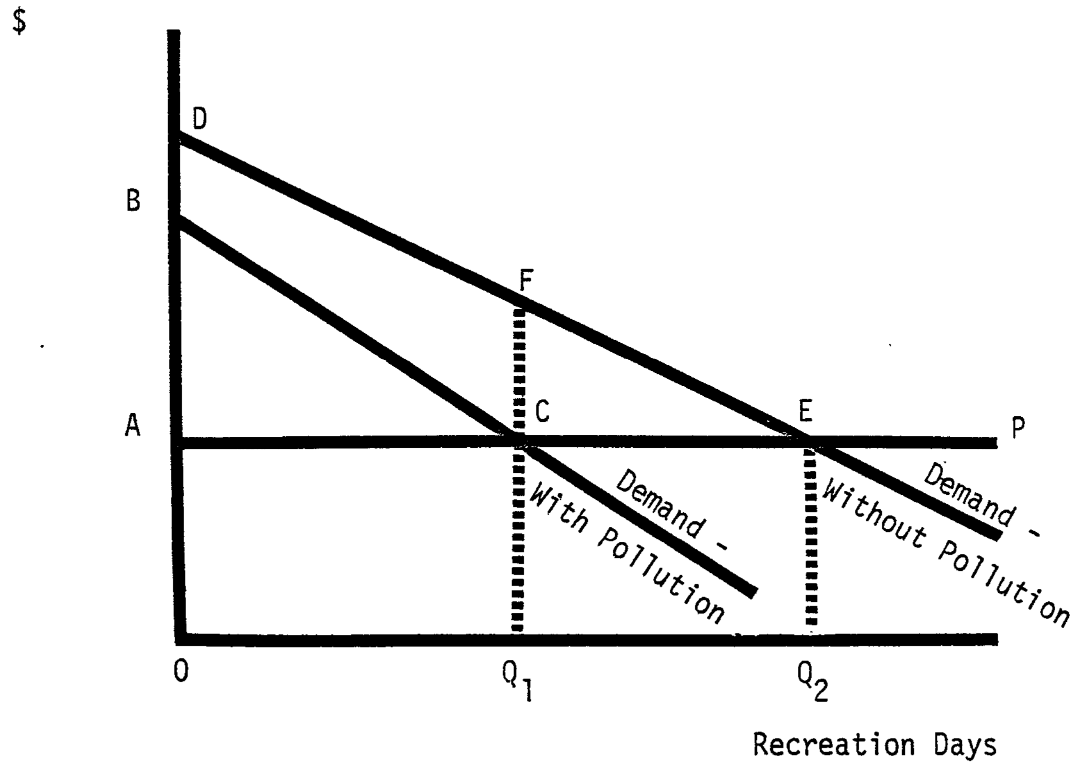

Figure 11-3. Recreational Benefits of Water Pollution Control

The net value or rent attributable to this recreation site is the area A-B-C. This is a consumer surplus measure of value. Now, let us assume that a pollution control program increases water quality at this site. In economic terms, the effect is to shift the demand curve out and to the right - the new demand curve as shown in the figure. The net economic benefit of this cleanup is the increase in consumer surplus, i.e., the area between the two demand curves, B-C-E-D.

The net benefit can be divided into two categories. The first is the increase in utility or consumer surplus to those 0-Q_1 users who were using the facility even when polluted. This is the area B-C-F-D. This area represents their increase in willingness to pay to maintain present use rates at this recreation site rather than do without. In addition, the greater attractiveness' of this site relative to alternative recreation sites and alternative consumption activities, other than recreation, results in an increase in recreation days at this site equal to Q_1-Q_2. There is a benefit associated with this increase in use which is equal to the area C-E-F.

In utilizing such a measure of benefit, there is no need to take into account changes in recreation use at other sites, savings in travel cost, or whatever. These are all reflected within the B-C-E-D, benefit measure. When there are simultaneous changes in quality or availability at several recreation sites, the theoretical and empirical analysis becomes a bit more complicated. (Burt and Brewer, 1971).

As the analysis of Figure II-3 shows, changes in water quality will be associated with both changes in willingness to pay and changes in quantity of participation. This suggests that the simultaneous pursuit of two research paths might be most appropriate. The two are a national recreation participation survey incorporating socioeconomic variables as well as quality and quantity availability variables, and micro efforts to measures shifts in the demand curve for specific sites as water quality changes.

G. CONCLUSIONS

Four questions were raised at the outset of this paper. The first was: "Would national benefit estimates be useful?" In Section B, several important environmental policy issues were described which would certainly be illuminated by better information on benefits. Even when environmental policy issues are not made in accordance with a strict benefit cost rule, 'benefit and cost magnitudes are still important considerations in environmental decision making.

The second question was: "Will the state of the art permit the development of national estimates of benefits?" In my judgment, the economic theory and analytical techniques for valuing benefits for most classes of benefits are relatively well developed. There are still major unresolved theoretical and analytical issues with respect to valuing health and life benefits. But in other areas, for example, land value, travel cost approach to recreation, net factor income and productivity approaches, etc., the validity of the theoretical framework is now well established.

However, major problems remain at the interface between the economic dimensions of the benefits problem and those dimensions dealt with by the other sciences. There are major gaps in our ability to relate changes in use of the environment to changes in the environmental quality parameters. Examples include dose-response relationships for air and water pollutants, and relationships between water quality and recreation and fishing benefits.

It is fair to say that we know much more now about the nature and magnitude of air and water pollution control benefits than we did, say, five years ago. A review of Ridker's (1967) valiant effort is instructive in this regard, both in terms of the very crude conceptual framework and analytical technique and the almost non-existent data base he had to work with.

Turning specifically to air pollution, it is now possible to use existing techniques and data to obtain tentative estimates of air pollution health and property value benefits. Obtaining these estimates will involve the explicit use of value judgments and assumptions about certain magnitudes; and there will be some degree of uncertainty in the final figures. But part of the present state of the art includes a consistent framework and language for expressing this uncertainty in probalistic terms. Furthermore, these estimates will be reasonable in the sense that we are more likely to hit the correct figure by using these techniques than we are by drawing numbers out of a hat.

In the case of water pollution, medical knowledge of potential health benefits is simply inadequate. And for the major class of water pollution control benefits, recreation, the data base for relating water quality changes to changes in recreation use is not adequate. I would conclude that the state of the art and data do not permit reasonable water pollution control benefit estimates.

Are there any "hopeless cases?" For purposes of this discussion, we can define "hopeless" as a situation where the marginal cost of additional useful information is infinite. By this definition, there are no hopeless cases in the area of benefit measurement. Consider the problem of valuing human life. One might argue that although individuals do make decisions which imply money values for changes in life expectancy, these decisions reveal a multiplicity of values for different individuals and different circumstances. However, the search for a single unique value of life applicable to all situations is unnecessary. The absence of a unique single price or marginal value is a characteristic of all public goods, such as the demand for clean air and the unit value of recreation experiences. The point is that our understanding of the valuation problem can be improved by further research. It is in this sense that the problem is not hopeless.

There are, however, some insoluble problems in the area of benefit estimation. They are insoluble because they involve value judgments and fundamental questions of equity, not primarily questions of economic theory and measurement. We have uncovered three manifestations of this fundamental problem in the course of our discussion. First, there is no objective criterion for judging or evaluating different distributions of benefits and costs. Thus, although distributions of benefits and costs can be described for decision makers, this information cannot be incorporated into a comprehensive, objective decision rule without the prior specification of some set of equity weights. Second, our estimates of benefits are derived from the price information revealed by existing markets. This price information. derives its validity from the implicit acceptance of the existing distribution of wealth which produced the existing set of prices. If the present distribution of wealth is judged to be unacceptable on ethical grounds, no meaningful welfare statements can be derived from the existing price information. And third is the evaluation of potentially massive or catastrophic environmental damages which may occur at some more distant time in the future, i.e., so-called intergenerational effects.

The third question was: "Do recently published estimates of national benefits adequately reflect the state of the art?" In other words, do these estimates make the best use of presently available analytical techniques and data? Although a detailed answer is beyond the scope of this paper, in summary, the answer is "no". However, the cost of generating estimates which do reflect the state of the art would be relatively small; and in my judgment, the benefits of doing so justify incurring the cost.

The final question was: "HOW can present national benefit estimates be improved?" The recommendations for gathering additional data and more effective utilization of existing data are presented in the next section.

H. RECOMMENDATIONS

Recommendations for improvements in benefit estimation here fall into three categories: those dealing with improvements in the basic data and analytical techniques; those dealing with improved uses of existing data; and one proposing the initiation of *ex post* measurements of realized benefits.

1. Basic Data and Analytical Techniques

Earlier we distinguished between measuring effects and assigning of values, both necessary steps in the determination of benefit estimates. But in the key areas of mortality and morbidity from air pollution, and in the lesser areas of vegetation and materials damages from air pollution, as well as sports and commercial fisheries and production benefits from water pollution control, the measurement of these effects lies largely outside the realm of economics. And economists' efforts to assign values and estimate benefits in these areas must await better information on physical effects.

The apparent importance of health effects of air pollutants suggests a high payoff for more information on dose-response relationships. More effort should be devoted to large-sample carefully controlled epidemiological studies to examine both long-term chronic and short-term acute effects of air pollutants. An effort should be made to move beyond the inter-urban comparisons of the sort done by Lave and Seskin. Perhaps the population at risk data base developed for EPA can be used to carry out epidemiological studies disaggregated within urban areas. Also, some attention should be given to epidemiological studies of water pollution health effects. In particular, attention should be given to the problems of persistent organic chemicals, and viral pathogens in drinking water.

Research efforts to determine health and other kinds of effects should be designed so as to complement and support efforts to determine values. For example, sample surveys to determine morbidity effects due to air pollution should include questions to obtain socioeconomic data. This is important not only because socioeconomic variables are themselves associated with health status and must be controlled for in estimating health effects, but also because if these data are part of the effects study, they may facilitate the later assignment of economic values.

Research on the value of human life should be extended in two directions. First, the individual choice/willingness to pay model where one element of choice is a small change in the probability of death should be further developed. (Bergstrom, 1975; Zeckhauser, 1975; Thaler and Rosen, 1974). One important extension is to examine the implications of changes in the shape of the probability distribution of expected life. Second, government decisions and other collective decisions involving safety health, medical research, etc., should be carefully analyzed to determine the implied or explicit values placed on human life or changes in probability of death. This effort may give some insight into collective attitudes toward life valuations, and it may also stimulate efforts to achieve greater consistency among public sector decision makers in this area.

The U.S. EPA should commission a series of micro region-specific efforts to estimate the demand curves for specific recreation sites using the Clawson-Knetsch travel cost approach and to relate shifts in the demand curve to changes in various water quality parameters. This series of studies should be designed and coordinated so as to control cross studies for socioeconomic variables, the availability of substitutes and alternative sites, and other regional differences in recreation behavior. The objective of these studies would be to identify the underlying functional relationship between quality and willingness to pay for recreation experiences. If this effort is successful, it should be possible to generalize the results to additional sites and regions. This series of studies would emphasize the determination of the demand curve and evaluation.

Another study should address changes in the quantity of use on the basis of a large, carefully constructed survey of recreation participation. Earlier surveys have not adequately dealt with the quantity and quality of the available water based recreation sites and the availability and quality of alternative forms of recreation opportunity as determinants of water based recreation participation rates. If such a data base were established, and participation rates could be successfully related to the quantity and quality of recreation opportunity; then the prediction of changes in participation rates associated with specific water pollution control programs would be relatively straightforward. Of course, this approach would not reveal values or shadow prices; nor would it capture the change in utility of existing recreationists.

The model being developed by the National Planning Association under contract to the National Commission on Water Quality appears to be a very promising step in the right direction. However, it does not appear that that model can be adequately developed given existing time and resource constraints. That research effort should be broadened and continued at a generous level of support. Independently, a series of travel cost and similar studies should be initiated in an effort to determine unit values for recreation days, and, more importantly, the way in which they vary with changes in water quality and other attributes of particular recreation sites.

There should be carefully constructed experiments with the interview/questionnaire techniques for estimating willingness-to-pay for reduction in pollution. These experiments should be coordinated with studies based on other analytical techniques in an effort to provide a cross check or validation of benefit estimates obtained by different approaches.

2. Use of Existing Data

The Lave and Seskin air pollution-mortality regression equations should be used to predict changes in mortality by SMSA for changes in air quality necessary to meet national primary air quality standards. These estimates of changes in mortality should be combined with alternative assumptions about the value of human life to calculate a range of benefit estimates.

The Freeman-Rosen technique should be used to compute correct benefit estimates from existing property value studies. for individual cities. Also, it may prove useful to commission a series of new property value studies using improved measures of property value and a consistent theoretical model and empirical technique for all cities. These studies should be designed to identify the demand curve or willingness-to-pay curve for clean air.

A group of experts should be convened, perhaps under the auspices of the National Academy of Sciences, for the purpose of developing a comprehensive estimate of national benefits of pollution control. The group should be comprised of professional researchers with backgrounds in environmental economics, the economics of project evaluation, econometrics, epidemiology, environmental health, limnology and marine biology, agricultural sciences, and engineering. The group should be asked to review all of the available literature and on-going research on the effects of all classes of pollutants, and to compile their best estimate of national benefits of pollution control for each of the major polluting substances.

The group should utilize a consistent framework for defining and measuring benefits, and consistent techniques and methodologies for moving from building block studies to national estimates. It should utilize all available data, making use of their expert judgments as to relative quality and accuracy of parameters and relationships from different studies. The group should be asked to make recommendations to guide further research to close gaps in information that are identified by the group. A new group should be convened every three to four years in order to review new data and to prepare new national benefit estimates.

3. <u>Ex Post Evaluation</u>

A careful and comprehensive program of *ex post* analysis of pollution control benefits should be developed and implemented. The period of the seventies will have been characterized by a major commitment of resources to air and water pollution control. It would be penny-wise and pound-foolish not to plan now to allocate one or two percent of the total funds to be spent on pollution control toward measuring and evaluating what we will have bought with that massive expenditure.. In one sense, the nation is embarking on a large-scale socioeconomic experiment in altering environmental conditions. We should take advantage of this experiment with a carefully thought out and comprehensive program of data gathering and analysis.

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III. BENEFITS OF AIR POLLUTION CONTROL

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A. INTRODUCTION

This section presents the purpose and scope of this paper,. the techniques for estimating air pollution control benefits, and finally, the organization of this paper.

1. Purpose and Scope

The purpose of this paper is to review and assess the methods available for modeling and measuring the economic benefits of air pollution control. Models of the economic behavior of beneficiaries of air pollution control could be increasingly used to untangle the various financial, economic, and environmental issues relevant to proposed control efforts. Nevertheless, in some instances, attempts to apply these models may already have gone beyond the general understanding of their analytical foundations and their appropriate roles in decision making. In order to evaluate the extent to which this might be true, it is necessary to have a clear idea of the possible purposes of a model of the behavior of beneficiaries of air pollution control.

Fundamentally, a model can have any one or more of three objectives:

- Enhanced understanding of the phenomena being investigated
- Improved ability to predict the future courses of important variables at various levels of disaggregation
- Improved basis for analyzing the economic consequences of specific alternative control policies.

Generally speaking, all three objectives are served better by any model encompassing a greater range of phenomena or one characterized by variables more closely corresponding to observable phenomena, or one permitting the use of more powerful and readily applied estimation techniques.

Among these three objectives, the first is most likely to be of interest to the professional researcher, while the latter two assume greatest relative importance for the decision maker. Moreover, the first requires more emphasis upon formal analytical comprehension, whereas the latter two emphasize empirical implementability. In those parts of economics relevant to the assessment of the benefits of air pollution control, there. has frequently been inadequate attention by analytical investigators to possibilities of improved empirical implementation. On the other hand, decision makers have overly encouraged the production of empirical efforts lacking proper analytical foundations. Recognizing these deficiencies, there now appears to be a judgment that research into the economic benefits of air pollution control can ultimately have little to contribute to the improvement of decisions about air pollution control. This paper will attempt to temper this judgment.

The framework of analysis adopted throughout this paper is the market, the interaction of buyers and sellers. The particular interest is those markets in which air pollution is thought to have a substantive impact on buyer and seller valuations. The manner in which the valuations expressed in these markets can be used to infer the value of air pollution control is discussed at some length. Substantial attention is given to the modeling complications introduced by special features of markets such as health and real property in which air pollution is thought to play a significant role. Among these features are multi-dimensional heterogeneity (in which the combination of characteristics embodied in each unit of a good is more or less unique to that unit), costly information, costs of market participation, and institutional and time constraints.

The neglect of these factors results in the omission of entire classes of air pollution control benefits stemming from the amelioration of intertemporal externalities and uncertainty about future levels of air pollution and its effects. This may mean that substantial biases are built into current estimates of air pollution control benefits, even if these current estimates have been established in an analytically and empirically sound fashion.

2. Estimation of Benefits

Estimating techniques employ one of three alternative measures of benefits:

- Alternative cost
- Opportunity cost
- Willingness-to-pay.

The first of these has been employed most frequently because of its great simplicity. However, its failure to consider adjustments that the sufferer can make in response to the presence of air pollution means that it will nearly always yield estimates of benefits that are biased upward. Moreover, because users generally do not employ an explicit analytical model, the approach yields little, if any, information about behavioral phenomena, the future course of important variables, or the consequences of specific alternative control policies.

In contrast, opportunity cost and willingness-to-pay measures require the construction of explicit analytical models of the phenomena being studied. Consequently, investigators with a background in formal economic analysis who are not under severe time constraints tend to employ these two measures. The research problem then becomes primarily one of comprehending economic, rather than physical or biological relations. The investigator is able to describe the behavior of the price or value of air quality with respect to various physical, biological, and economic parameters. Analytical models of health markets, property markets, etc., employing opportunity cost or willingness-to-pay measures are amenable to empirical treatment with either available data or data that can plausibly be obtained. One must, however, be moderately less sanguine about the availability of data to implement models in which uncertainty or intertemporal externalities have a substantive role.

Whatever the analytical and empirical quality of the benefit estimates thus far obtained, they rarely, if ever, make clear the uncertainty of the estimates themselves. All benefits assessment efforts should generate probability, distributions for whatever input variables are relevant and then aggregate these distributions to produce a probability distribution for the output measure, air pollution control benefits. Doing so would reduce the amount of useful information that is thrown away and would reduce the susceptibility of benefits estimates to criticism.

In addition, a number of short-term analytical and empirical approaches could yield rapid improvements in the state-of-knowledge. These include:

- Development and empirical implementation of general equilibrium models of property values
- Adoption and empirical implementation of a household production function framework for health effects studies
- Input productivity studies with special emphasis upon human factors of production
- Adoption of economic, rather than physical or biological, perspectives for the construction of environmental quality indices
- Adoption of new techniques from mathematical statistics to test the functional forms of expressions employed to estimate benefits
- Testing of procedures intended to cause interviewees to reveal their true preferences
- Increased use of algorithms intended to enhance the investigator's ability to discriminate among variables

that might contribute to variations in the values assumed by another variable

- Use of sophisticated econometric models of agricultural markets.

3. Organization

The next section presents the conceptual foundations of benefits assessment for any air pollutant and discusses the issues that must be resolved in applying these foundations to the analysis of individual air pollution control decisions. The third section describes each of the primary methods that might be used to estimate the benefits of air pollution control. An attempt is made throughout to relate these methods to a conceptual framework or a model and the practical questions, including data availability, associated with using each method are raised.

The fourth section compiles the most recent empirical efforts and reviews the content of these efforts in terms of the earlier commentary on conceptual foundations and empirical procedures. The last section reviews briefly the role and prospects of benefits assessment in policy decisions and argues for an increased allocation of research effort to the solution of specific analytical problems.

In order to provide the reader with some appreciation of the motivations underlying the occasionally more abstract discussions in the preceding sections, the attachment contains a discussion of the economic benefits for the participants in a single activity of controlling a single class of pollutants in a particular locale.

B. CONCEPTUAL FOUNDATIONS

This section presents the conceptual foundations for assessing the benefits of controlling any air pollutant and takes up the issues that must be resolved in applying these foundations to the analysis of specific control decisions. The presentation covers the motivations for measuring benefits, measurement techniques, and sources of benefits.

1. Motivations for Measuring Benefits

Air pollution control benefit assessments are intended to aid the public decision maker in formulating policy. If neither more nor less meaning is to be attached to these assessments than their underlying analytical foundations justify, then the decision maker must be sensitive to the limitations as well as the strengths of these foundations.

Cost-benefit analysis is an attempt to ascertain the socially valuable resources and services to be gained and lost in the attainment of any particular state of the world. In each state, market prices alone are presumed to embody all relevant information about relative scarcities and to be a sufficient means of allocating resources to their socially most highly valued uses. Price is assumed to be the sole mode of allocation used in voluntary interactions of buyers and sellers. Markets are pervasive; that is, all gains from exchange are quickly exhausted. Price is thus a sufficient measure of social as well as private value. In effect, the objective of cost-benefit analysis is to ascertain what the price structure of any particular state would be when markets are pervasive-.

Sophisticated proofs are available in the economics literature showing that states of the world attained in a system in which markets are pervasive are Pareto-efficient: the net social value of output is maximized because no one individual's welfare can be enhanced without-reducing the welfare of another individual (Arrow and Hahn, 1971). The price structure to be ascertained via cost-benefit analysis is therefore a Pareto-efficient price structure. It follows then that, insofar as benefits assessments are used by the decision maker as information inputs in policy decisions, he is making the judgment that the benefit valuations established through strictly voluntary exchange in a setting where markets are pervasive are at least one useful means of weighting the alternatives he has before him.

In the practical world outside economics textbooks, all gains from exchange are not exhausted because markets are, in fact, not pervasive. Institutionally fostered monopolistic advantages, technological externalities, such as air pollution, and consumption and production indivisibilities persevere even though their very existence implies the presence of potential gains from exchange. In a general equilibrium setting in which the activities of all pairs of buyers and sellers are interconnected, the presence of an inefficient price structure in one market implies a similar presence in all other markets. If efficiency is defined only for circumstances in which markets are pervasive, and if the activities of all pairs of buyers and sellers are interconnected, then all real observable price structures must be inefficient.

The activity of benefits assessment, when employed for public policy purposes, is a direct recognition that markets for certain goods and services are either nonexistent or incomplete. These goods and services are therefore valued inaccurately in the sense that their market prices diverge from efficient levels as defined by a world of pervasive markets. Benefits assessment employs various techniques to infer the equivalent prices of these non-marketed goods and services from information embodied in the observed market prices of marketed goods and services that are in the same production or consumption process as the non-marketed entity or which are substitutes or complements to it.

The extent of inefficiency reflected in these observed market prices is typically unknown. Unless an empirically implementable general equilibrium model of the economy is available, the extent of inefficiency (remembering that efficiency is typically defined only for a world of pervasive markets) is inherently unknowable. However, one does not do serious violence to accurate benefits assessment if one imposes separability conditions that permit dimissal from consideration of all markets whose goods and services are plausibly only remotely connected to the good or service for which benefits assessments are being performed.

Of course, a contribution to the description of the efficiency benefits of air pollution control need not be the sole or even one of the reasons why a decision maker wants benefits assessments performed. After all, any benefits assessment is simply a description of the price structure effects of a particular change in the state of the world. It is therefore readily used also to describe the effects of a change in air pollution control upon the distribution of income, government tax revenues, or any of a number of other pecuniary and economic questions of interest. Nevertheless, since all of these effects are influenced by the price structure of the market for the services of the atmospheric resource, as well as the price structures of closely related markets, analytically sound descriptions of these effects also require the construction and empirical implementation of a general equilibrium model.

2. Measures of Benefits

Having recognized the type of world to which economic efficiency is generally meant to refer and the implications of this reference for the construction and empirical implementation of models intended to measure air pollution control benefits, it remains to make explicit exactly what is meant by the term "benefits". First, it is necessary to be absolutely clear that the parties to whom the benefits of air pollution control are presumed to accrue are individual persons. Social benefits are simply some aggregate of individual benefits: there does not exist in cost-benefit analysis a concept of the society having an existence independent of the individuals who compose it.

Second, there exists a consistent, discoverable relationship between a change in ambient air pollution levels and the change in the individual's utility or welfare. The latter is interpreted as the benefits accuring to the individual. Central to the logic of this relation is the idea of consumer's surplus. This states that the individual continues to purchase additional units of the ith good until the marginal utility of the additional unit is just equal to the marginal utility of the money he must pay to obtain the additional unit. That is, the individual will be indifferent between keeping his money and consuming an additional unit of the good when the marginal utility of the additional unit is equal to its market price. The difference between what the individual is willing to pay, as determined by the marginal utility he attaches to the unit, and what he has to pay, as determined by market price, is the consumer's surplus for the unit. The sum of the surpluses for all these units is total consumer's surplus.

This concept is illustrated in Figure IV-1, where DD is the demand function, the locus of points depicting the consumer's

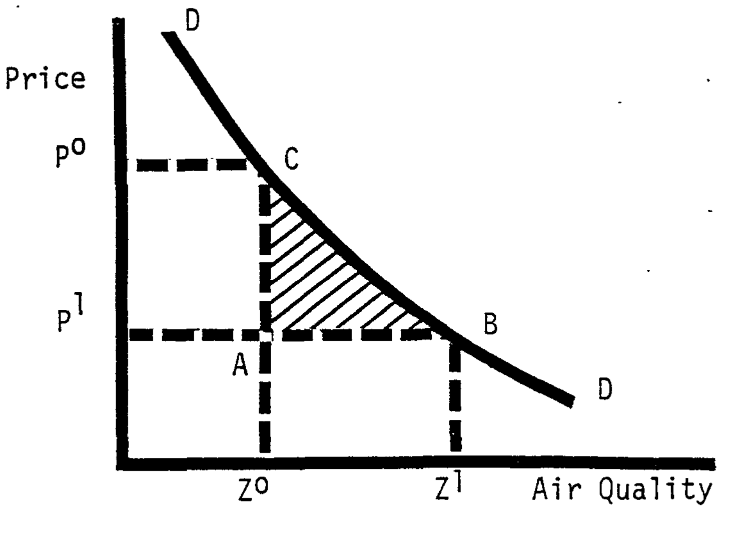

Figure IV-1. Representation of Consumer's Surplus marginal willingness to pay. The cross-hatched area, ABC, represents the consumer's surplus associated with an improvement in air quality, Z, from Z^0 to Z^1.

In a very important paper, Willig (1974) has shown recently that, in most applications, the difference between the observable consumer's surplus area, ABC of Figure IV-1, and the theoretically correct consumer's surplus of the income-compensated demand function is accurately described as trivial. Willig's (1974) results vindicate analytically the conceptual foundations and great practical value of the consumer's surplus methodology so frequently employed in studies of the benefits of air pollution control. It should nevertheless be noted that there exist several different measures of consumer's surplus, most of which are distinguished by the path the consumer is presumed to follow from one equilibrium position to another. For presentation of a set of criteria with which to evaluate these various measures, see Mohring (1971).

The empirical establishment of the observable surplus becomes considerably more complicated if alternative formulations of the consumer's problem are employed. For example, rather than directly entering the utility function, air pollution might reasonably be viewed as influencing the cost to the consumer of using goods capable of providing utility. Thus, if the absence of respiratory problems is a good from which a consumer derives utility, he will have to expend a greater quantity of valuable resources attaining this absnece in New York City than in Laramie, Wyoming.

An alternative formulation would have the consumer obtain utility directly from the absence of air pollution while also permitting air pollution to affect the costs of other activities or goods from which he obtains utility. Estimation of consumer's surplus using this formulation is more complex than using the traditional formulation, because the goods or activities the use of which air pollution is presumed to affect (e.g., medical services) are treated as inputs into commodities (e.g., the absence of respiratory problems) that are the ultimate objects of the consumer's preferences. In general, even though these formulations will usually increase estimation problems, failure to adopt them in circumstances where reality warrants their adoption would introduce specification errors and thus possibly result in serious errors in the benefit estimates obtained.

As these progressively more complex formulations of the consumer's surplus problem make intuitively clear the greater the generality and realism of the formulation, the greater the difficulty likely to be involved in empirically implementing the propositions falling from the formulation. Nevertheless, because both informational and modeling constraints prohibit the consideration of the full range of commodities, activities, and conditions influencing consumer behavior, some subset of these things must be taken as given. An explicit statement of the formulation on which the empirical effort is based is thus highly desirable. Only then is the reader able to ascertain whether the estimation techniques and the data base employed fit the problem. Equally important, the reader is unable to assign a unique meaning to the empirical results, unless he is made fully aware of the conceptual framework from which these results come.

3. Sources of Pollution Control Benefits

Most discussions of air pollution control benefits explain the existence of economically excessive ambient pollution concentrations in terms of static nonpecuniary externalities. That is, one economic agent's production or utility relations are said to include levels of air pollution chosen by other economic agents, without regard to the effects on the first agent's welfare. The damaged agent in these discussions is implicitly presumed to know with certainty either the magnitude of the effects caused by the air pollution and/or the level of air pollution. Moreover, the reader is customarily permitted to assume that the activities of the pollution perpetrator and the responses of the sufferer to this pollution are contemporaneous.

The restriction of the discussion of the analytical reasons for the existence of air pollution control benefits to static non-pecuniary externalities might explain why two plausibly important causes of air pollution control benefits, intertemporal externalities and uncertainty, have been rarely considered. Their neglect may mean that substantial myopic biases are built into current estimates of benefits.

There appear to be a number of air pollution effects characterized by either or both of the above causes. For example, rain containing acid sulfates may ultimately alter the forest ecosystems of entire regions. Certain long-lived synthetic chemicals, once widely dispersed throughout the economy, and thereby the natural environment, may pose carcinogenic and mutagenic hazards for future generations. An economic agent's activities at one point in time impose constraints upon other, economic agents in the future. Insofar as there exists imperfect knowledge of future events, these externalities are a problem worthy of empirical attention.

The air pollution effects associated with intertemporal externalities and uncertainty are characterized by some or all of the following attributes:

- Information asymmetry
- Effects uncertainty
- Public-good type risks
- Low-probability catastrophic losses
- Irreversible effects.

Substantial discrepancies exist in available information about the benefits of increasing an activity, as opposed to the benefits of reducing it. The benefits of automotive travel are relatively easy to calculate; the benefits of reducing automobile travel and its associated air pollution, noise, and aesthetically loathsome landscapes are generally more difficult and expensive to ascertain. For many air pollution phenomena, there is a nearly complete absence of knowledge about the response of physical and biological systems. For example, the overall effect on the earth's climate of increased particulate loadings of the troposphere is highly uncertain. Similarly, the influence on human health of increasing ambient loadings of acid sulfates . has not been adequately defined.

The actual or potential risks caused by certain activities are indivisible as between and among economic agents. Moreover, they are frequently borne by very large groups of these agents, including future generations. These groups are unable to reject the risks because they are bound up in a common property resource, e.g., the atmosphere. As used here, risk may refer not only to a lack of complete certainty about one's future wealth,but also to not knowing if one will be alive to enjoy this wealth.

With current information, there exists a probabilistically small possibility of catastrophic or large-scale losses. For example, one potential result of burning large quantities of high sulfur fuels in England is the possibility of greatly and detrimentally altering the forest ecosystems of the Scandinavian countries through formation of acid rain.. There is also a possibility that the effects of a particular activity are physically impossible to reverse or cannot be reversed at reasonable cost. Mutagenic changes probably have this characteristic.

The importance of issues embodying substantial uncertainty or ignorance, and therefore the extent to which they are worthy of substantial research effort to assess their benefits and costs, depends in large part upon the decision strategy adopted. If a once-and-for-all commitment is to be made to undertake or fail to undertake an activity, then the likely effects deserve to be specified and measured rather closely. But if a sequential decision procedure is to be followed, the accumulation of knowledge can be delayed. One can then live with a fairly high degree of uncertainty in the present. The cost of an error in choice is not likely to be as great, because it will be relatively less costly to reverse course.

Setting intertemporal externalities and lack of basic knowledge about air pollution effects aside, there is an additional way in which uncertainty might plausibly enter calculations of air pollution control benefits. In the more mundane localized materials damage, property value, interview, and health effects studies of common urban air pollutants that form the bulk of air pollution control benefits studies, the uncertainty of potentially affected individuals about future air pollution levels and the possible influence of this uncertainty upon air pollution control benefits is usually not even mentioned (Crocker, 1971; National Academy of Sciences, 1974).

The disutility the affected individual attaches to future air pollution dosages has been treated as identical in situations where perfect foresight is lacking and in situations where it is present. An affected agent's behavior at a point in time has therefore been viewed as invariant with respect to the probability of error in his forecast of expected air pollution dosages and/or effects. Yet an extremely voluminous analytical and empirical literature is available in economics indicating that in most everyday circumstances, individuals are risk-averse, i.e., uncertainty is costly.

When one admits that one component of air pollution damages may be due to uncertainty of the affected individual about current and future air pollution levels and effects, it is apparent that individual damages from air pollution dosages are by no means independent of the process by which expectations about future dosages and effects are formed. That is, realized damages are but present representations of positions taken in the past in response to expected air pollution dosages and effects. Most empirical air pollution control benefit studies have assumed that sufferer adjustments to changes in air pollution dosages and effects are instantaneous. A more appealing hypothesis is that expectations about future air pollution dosages and effects adapt to changes in present dosages and effects only after some lag in time. Thus, if a change has any permanent effect at all, the effect is not registered all at once but is instead distributed.over several time periods.

C. EMPIRICAL PROCEDURES

This section reviews some general formulation employed in estimating the benefits of air pollution control. The topics include methods of estimating benefits, availability of data, expression of uncertainty in results, and aggregation procedures.

1. Methods of Estimating Benefits

The general formulations customarily employed in the estimation of air pollution control benefits are:

- Alternative cost
- Opportunity cost
- Willingness to pay.

The alternative cost formulation is employed most frequently because of its simplicity and avoidance of complex economic analysis. The procedure begins with determination of the physical effects of an activity. For example, an agronomist might construct a dose-response function relating ambient concentrations of acid sulfates to the yield of a particular agricultural crop. These effects are then valued in monetary terms. The assigned money value is that minimum cost which would have to be borne in order to return the affected entity to its original state. This implies that all substitution possibilities and other adjustment processes available to the owner of the affected entity are dismissed from consideration. Losses therefore tend to be biased upward in the case of reductions in air quality, and benefits tend to be biased downward in the case of improvements in air quality. If, and only if, no ready adjustments are possible for the owner of the affected entity is the alternative cost formulation a reasonable approximation of the actual losses or benefits.

Wherever these substitution possibilities and adjustment processes are accounted for, the researcher has adopted an "opportunity cost" formulation. In the case of a decline in air quality, a net loss measure is thus obtained. For example, the researcher studying the influence of smog on the behavior of outdoor recreationists would explicitly take into account the stock and the unit price of substitute recreational opportunities. By taking these opportunities into account, the researcher is, in effect, deriving the minimum amount the recreationists would accept to be willing to be subjected to a change in air quality. The presumption is that title to the air resource is held by the parties who would be affected by the change rather than by the potential perpetrator of the change.

Finally, the "willingness-to-pay" formulation underlies the discussion of the entire previous subsection. As noted earlier, this formulation involves the determination of what individuals would be willing to pay in order not to be subjected to a change in air quality. Therefore, the researcher is assuming that title is held by the perpetrators, rather than by those who will be affected.

The ordering of the magnitudes of these formulations can differ from one set of circumstances to another. Frequently, estimates of losses associated with reductions in air quality using the opportunity cost formulation exceed the estimates resulting from the willingness-to-pay formulation. This is due to the difference in fundamental entitlements and therefore the wealth positions of the parties. Estimates obtained using the alternative cost formulation as opposed to the opportunity cost formulation follow no consistent pattern with respect to relative magnitudes. For example, one could reasonably argue that the money necessary to compensate outdoor recreationists for increases in the amount of smog-damaged forest might be relatively small when compared with the alternative of returning the forest to its original state.

The alternative cost method is nearly always used in the "technical coefficients" approach (Anderson and Crocker, 1971). Also, the widely quoted Lave and Seskin (1971) study on the economic aspects of the health effects of air pollution is best described as an alternative cost study. Examples of studies that do not involve air pollution, but show the empirical practicality of willingness-to-pay studies applied to health effects are provided by Acton (1975), Davis and Russell (1972), Feldstein (1971), Grossman (1972), Phelps and Newhouse (1974), and Rossett and Huang (1973).

2. Availability of Data

The extent to which each of the three alternative measures have been employed in investigations of air pollution control benefits has been determined by three factors: the availability of data, the availability of time, and the background of the investigator in formal economic analysis. Use of the alternative cost measure typically requires little background in economic analysis, while allowing the use of accumulated skills in the natural sciences. The necessary economic "analysis" involves little more than the weighting of physical and biological relationships by readily observed market prices.

The investigator has the opportunity to draw upon the more sophisticated developments in economic analysis when he chooses to employ the opportunity cost or the willingness-to-pay measures. Rather than simply using observed market prices as determined by unknown and presumed irrelevant forces, the opportunity cost and the willingness-to-pay measures compel the construction of models of the implicit market for air quality, thus permitting the investigator to describe the behavior of the price or value of air quality with respect to various physical, biological, and economic parameters.

The extent to which observations must be available on the actual values assumed by the elements of each of these three sets of parameters will, of course, vary according to the problem being investigated. It is true, nonetheless, that the available secondary data and readily acquired primary data for the economic parameters of a great many problems have by no means been fully exploited. For example, great masses of data are available in publications of the U.S. Department of Agriculture and other sources allowing the empirical implementation of opportunity cost models of air pollution damage in agricultural markets. Similarly, large secondary data collections from Federal, state and local sources make possible the estimation of hypotheses derived from willingness-to-pay models of property markets.

Even opportunity cost and willingness-to-pay models of the effect of air pollution upon health are amenable to empirical treatment with either available data or data that can be readily obtained. The widely known CHESS studies of U.S. EPA would have provided enormously more valuable information on the health impacts of air pollution if they had initially been designed by economists as well as by biomedical people.

In summary, analytically sophisticated and empirically implementable models for which data are available or can be readily generated do exist. This is not to say that all the economic benefits of air pollution control are readily susceptible to empirical estimation. The point is that a great deal more can be done. The decision maker must judge whether the results are likely to be more useful than estimates obtained via the simplistic alternative cost formulation, or even the intuitive or experiential approaches that are used frequently in political decisions.

The above comments about the availability of data allowing the empirical implementation of opportunity cost and willingness-to-pay measures apply mainly to static externalities. One must be less sanguine with respect to data availability for empirical implementation of economic analysis of intertemporal externalities and risk aversion. The latter is that facet of human preferences responsible for the existence of benefits from the reduction of uncertainty about air pollution effects and levels.

Two approaches have dominated economists' and psychologists' attempts to measure risk aversion. In the first, lotteries are established in a controlled laboratory setting and the investigator, usually a psychologist, attempts to extrapolate the results to real-world situations. Certainly, one can generate a great deal of data in this manner. However, the degree of correspondence between the controlled laboratory and real-world situations is not always apparent. (Lichtenstein, 1965; Pruitt, 1962).

The second approach has been fairly widely used by economists. Here, the observed behavior of individuals in their everyday pursuits is used to infer the value they attach to the reduction of risk to fortune, health, and life. (Fama and MacBeth, 1973; Oi, 1975; Brown and Enke, 1972). The approach is appealing to the professional economist, because it permits the construction of models of the behavior of economic agents, the formal derivation of testable propositions, and the application of opportunity cost or willingness-to-pay measures of benefits. However, its usefulness is limited by data availability, at least with respect to health and life.

A number of difficulties may be attributed to the public good type risks that characterize air pollution. These are borne by large groups of economic agents, including future generations. That is, the population exposed to deleterious ambient levels of air pollution typically involves a wide cross-section of ages, incomes, medical histories, employments, and other factors,

The most available data, permitting ready inferences about economic agents' voluntary willingnesses-to-pay to avoid risk to health and life are found in the area of industrial safety. However, since netiher the medical backgrounds nor other personal attributes of industrial workers are representative of the population of a typical urban area, the extrapolation of these workers' health and life risk valuations to entire human populations can be done only with some trepidation. On the one hand, industrial workers may, as a group, simply have less or more innate aversion to risk than do other identifiable groups within the entire population. In addition, some groups, such as university professors and government or private bureaucrats, may have less accumulated experience with situations posing risks to health and life. Given more experience, their attitudes may be altered.

There exists at least one source of readily available data on the risk aversion of representative individual economic agents that has not been fully exploited. This involves the voluntary consumption or use of goods which carries obvious and generally acknowledged risk to health and/or life. For example, certain automobiles are widely known to be safer than other automobiles. In effect, the safety features of the automobile are weighed by the purchaser against its other features and its price relative to other automobiles and perhaps other modes of transportation. The question, nevertheless, remains as to how one extrapolates the agent's valuation of risk to health and life in the context of an automobile to his valuation of risk to health and life in the context of air pollution.

Intertemporal externalities are, of course, intimately tied to the presence of uncertainty and risk aversion. These externalities are complicated, however, by the integral part played in their determination by irreversible effects and the passage of time. Analytical efforts in this area have thus far concentrated upon the nature of the adjustments that must be made in traditional benefit-cost evaluations of alterations of natural environments in order to account for irreversibilities, uncertain future effects, etc. However, these efforts typically fail to supply exact quantitative adjustments for these evaluations, nor do they provide computational algorithms indicating the form, type, and quantity of data required for empirical implementation. Without such knowledge, one cannot state whether the requisite data is, in fact, already available or easily obtainable.

Nevertheless, it should be noted that, in particular cases not involving air pollution, some investigators have managed to implement empirically at least a part of the relevant analysis. (Krutilla and Fisher, 1975). These partially successful empirical efforts have occurred in geographical areas where detailed data have been available on likely future technological developments, environmental carrying capacities, and demand patterns for uses based on the existence of a natural environment, as well as for uses involving the transformation of a natural environment.

3. Expression of Uncertainty in Results

Even if the world is a purely deterministic place, it is indeed unlikely that it would ever be worthwhile to accumulate enough data about air pollution problems to eliminate all possible sources of error in benefit estimates. Errors in measurement and simple absences of observations on key variables would persist. In spite of this rather obvious point, estimates of air pollution control benefits are, for the most part, compiled and reported in terms of a single outcome that fails to take account of valuable information about the extent of uncertainty in the reported estimates, The commonly accepted procedure in benefits assessment calls for the calculation of the benefits from each alternative action and for the use of political and economic criteria to choose among these on the basis of expected returns. But except by chance, single-valued benefit estimates must always be in error.

The uncertainty problem discussed in this subsection occurs because many of the variables affecting an air pollution control plan are neither subject to the control of the decision maker nor fully captured in the empirical implementation of any model constructed by the benefit assessor. These variables include property rights structures, technological change, prices, micro-climates, etc. Hence, in contrast to commonly accepted procedures, benefits assessment that takes full account of uncertainty requires: judgments about the likely pattern of behavior of these noncontrollable variables; calculation of an entire set of outcomes or returns for each ambient air concentration; and criteria for choosing among concentrations on the basis of sets of possible benefits for each level of control.

On those occasions when uncertainty has been explicitly taken into account, range sensitivity tests have typically been used to account for lack of knowledge about the behavior of different relationships or the values assumed by particular parameters. Waddell (1974), for example, includes upper and lower bounds and "best guesses" for various air pollution damage categories. An alternative procedure is to generate probability distributions for whatever input variables are relevant and then aggregate these distributions to produce a probability distribution for the output measure, i.e., air pollution control benefits. In an interesting application of this latter approach, Mercer and Morgan (1975) have successfully applied the Weibull (1939) family of distributions, showing that the amount of valuable information made available to the decision maker is enhanced significantly (see also Pouliquen, 1970).

The probabilistic approach to presentation of benefit estimates has many advantages, not the least of which is that it permits the investigator to incorporate accumulated wisdom and intuition into the analysis in an explicit and communicable fashion. If research resources are scarce, individuals who have had long experience in working in an area frequently have a "feel" for the structure of the problem, which permits them to assign subjective probabilities to various outcomes. Some people argue that such evidence should be dismissed on the grounds that it is not "objective", but this argument is badly mistaken. It is difficult to understand why the objective specification of uncertainty should be so important, when the criteria used for choosing among alternative models and oftentimes the model choices themselves are subjective.

Another major advantage of the suggested probability approach is that it does not throw away useful information. For example, in attempting to assess air pollution damages to commercial crops, the biochemist might specify the "best" of several dose-response. functions relating crop yield to ambient concentrations of a particular pollutant. In the absence of a thoroughly coordinated research effort in which the economist specifies the variables, units of measure, and sampling procedures, it is possible that the biochemist's conception of best does not accord with that of the economist. It is then up to the economist, who usually is utterly illiterate in biochemistry, to translate the biochemist's results into something useful for purposes of economic analysis. By requiring that a probability be assigned to the various plausible outcomes, the impact of this decision problem can be greatly improved. (Crocker, 1975).

4. Aggregation Procedures

Any estimate of national air pollution control benefits is an index number. That is, a variety of relationships of multiple dimensionality are collapsed into a unique scaler measure. The process of the collapse or aggregation involves an exchange of detailed information about the form and structure of a set of problems in return for tractability and ease of comprehension. The best single source of information on the aggregation problem in economics continues to be Green (1964). The portion of Marschak and Radner (1972) dealing with the one-person team is highly instructive from a decision theory perspective. Fisher and Shell (1972) provide an excellent treatment of the place in index number problems of taste and quality changes, both of which are highly relevant to environmental quality problems.

For a limited number of purposes, it may be of interest to obtain estimates of the total nationwide benefits accruing from air pollution control. An aggregate benefit estimate may provide policy makers with an easily grasped idea of the magnitude of the problem and may therefore give some indication that additional or reduced research resources should be devoted to ascertaining the economic effects across space and time of alternative control strategies. As a possible component of the national accounts, these estimates may also be useful for macroeconomic decision making purposes since they provide some evidence on how the presence of air pollution and attempts to control it alter the nation's aggregate net productivity. An effort, currently underway at the National Bureau of Economic Research to find ways to include environmental quality costs and benefits in the national accounts, is partially described by Peskin (1974).

However, attempts to apply aggregated economic response functions or aggregated magnitudes to local or regional air pollution decision problems introduce sources of error that can lead to substantial discrepancies between expected and realized economic results. These sources of error may remain even if the aggregated functions or magnitudes are used as no more than the points from which disaggregation to the local level is initiated. The initial process of aggregation over locales, and subsequent disaggregation back to locales, may destroy knowledge of the various transformation and substitution possibilities and relative consumer valuations of alternatives in each locale. That is, the weights used to determine the contribution of each type of sufferer and each locale to the aggregate measure may not correspond to the relative weights sufferers in each locale attach. The application of the same set of weights across different sufferers and locales assumes that all sufferers and locales are identical and that existing differences among sufferers and locales will remain unchanged as air pollution levels change, These are indeed strong assumptions.

Existing estimates of the national benefits of air pollution control combine a large number of heterogeneous disaggregated studies dealing with vegetation and materials damages, property values, health effects, and opinion surveys. A majority of these studies employ alternative cost measures, although willingness-to-pay measures have been widely used in the property value studies. The process of aggregation typically employed to obtain these estimates is exemplified by the procedures Waddell (1974) employed to obtain an estimate of aggregate national. (residential) property value damages.

Waddell first reviewed a collection of studies that had estimated marginal purchase price functions with respect to sulfur oxides and/or suspended particulates for eight different cities. Interpreting the values of the air quality parameters in these several studies as measures for the average household in each study of equilibrium marginal willingness-to-pay at given air quality states and with given demand functions for air quality, he selected a value within the range of these estimated values. By selecting this value within the range of values, he assumed that what was interpreted as the equilibrium marginal willingness-to-pay was the same for all households in all cities. Then, using the further assumption that this assumed equilibrium marginal willingness-to-pay was in fact the actual marginal willingness-to-pay for all air quality states, he multiplied the constant marginal willingness to pay by the number of households and the number of air quality states to obtain an estimate of aggregate national air pollution damages.

In effect, Waddell assumed that the decision problem of each and every household in each urban area of the country could be represented by Figure IV-2, where b is the marginal willingness-to-pay, Q is an air quality level, D is the aggregate national air pollution damage, $\partial P/\partial Q$ is the marginal purchase price function, and $\partial D/\partial Q$ is the function representing marginal willingness to pay for improvements in air quality. Since $\partial D/\partial Q = b$ is invariant with respect to changes in air quality, calculation of that willingness to pay involves only the multiplication of b by whatever change in air quality is postulated. Thus the value to the depicted household of an improvement in air quality (Q** - Q*) is simply b(Q** - Q*), and the sole distinction one needs to make among households in order to calculate aggregate national damages is to account for the location of each household on the Q axis.

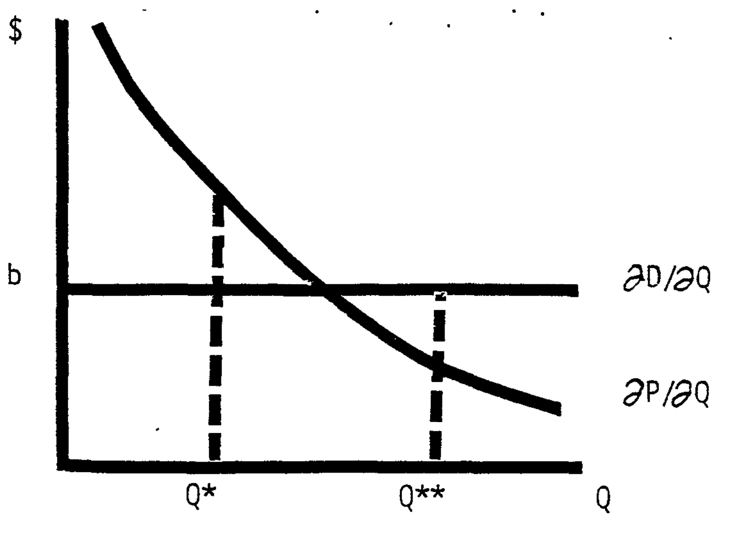

Figure IV-2. Willingness to Pay for Improvement in Air Quality

The above discussion has been devoted to a single aggregation over individual households. Typically, however, estimates of national air pollution control benefits involve aggregation over multiple classes of pollutants, over time, as well as over households. scaler estimates of the national benefits of air pollution control may thus involve two or three distinct types of aggregation, each of which embodies unique assumptions about the similarities among the units undergoing aggregation. Thus, one must choose which type of aggregation is to be performed first in arriving at a scaler representing air pollution control benefits for households, for pollutants, and for time intervals. Moreover, in deciding how to perform the first aggregation, one must take into account how the aggregation for the second and third steps will be carried out.

Finally, it should be noted in passing that the entire discussion in this subsection has presumed that estimates of the aggregate benefits of air pollution control must be constructed from disaggregated, microeconomic studies. The presumption is that empirically measurable microeconomic variables and relations have been derived from microeconomic theory. Given these derivations, aggregated or macro-variables representing national benefits of air pollution control and national ambient air pollution levels have then been defined, Thus far, there has been no intensive analytical effort devoted to constructing an aggregate or macro-theory that will serve to make the macro-variables consistent with the micro-theory and micro-variables. At least in principle, the development of such a theory is by no means a hopeless task. The development of macro-economic theory and national income accounting is evidence of this.

D. SHORT-TERM IMPROVEMENTS IN BENEFITS ASSESSMENT

Most of the discussion to this point has been directed at improvements in the long-term strategy of benefits assessment research. This section seeks to make the reader aware of some theoretical constructs and empirical procedures holding tangible near-term promise. The topics are arranged in order, -from the more analytical to the more empirical.

1. General Equilibrium Models of Property Values

Rosen (1974) and Freeman (1974) have recently developed a conceptually improved method of obtaining aggregate national damage estimates that neither assume that the same set of weights applies to each locale and each individual, nor disregards the manner in which burdens are distributed across space, time and individuals. This method employs property value and attributes data for individual urban areas to ascertain a distinct marginal purchase price function for each urban area, using similar data and statistical techniques for each area. Having estimated the marginal purchase price function for each urban area, the data from each area are merged into a single data set. From this data set the relationship of air quality to marginal purchase prices and various household attributes such as income and age is estimated. The value of the parameter attached to the marginal purchase price variable can then be interpreted as the marginal willingness-to-pay for an improvement in air quality.

If the expression relating air quality to marginal purchase prices and various household attributes is nonlinear in the original variables, one can readily obtain scalar measures of marginal willingness-to-pay that can differ from one urban area to another. If this expression is linear in the original variables, one obtains a scalar measure of marginal willingness-to-pay that is constant from one area to another. Nevertheless, this two-stage procedure does permit the distinctive attributes of different urban areas and different households to enter into the determination of average marginal willingness-to-pay.

Summation over the marginal willingness-to-pay estimates for each city in the sample and extrapolation to the nation of the average sample marginal willingness-to-pay, if the sample is thought to be representative of all the urban property markets in the country, provides an estimate of aggregate national air pollution control benefits. This estimation procedure has been recently applied to a single urban area in an extremely interesting and innovative paper by Nelson (1975).

The procedure is soundly grounded in economic theory and is capable of capturing many elusive features of the market, such as multi-dimensional heterogeneity and assorted institutional constraints. In contrast to many other approaches that could be employed, this one can be implemented by widely and thoroughly understood statistical techniques. Finally, a multitude of data, most of which is isomorphic with the theoretical parameters, is readily available.

The Rosen-Freeman estimation procedure forgoes far less information than studies in the other benefit categories when aggregated to the national level. It thus becomes worthwhile to invest substantial analytical and empirical research effort in establishing the extent to which health effects, materials damages, etc., are registered in property values. Insight can then be gained into the decision value of the estimates likely to be obtained by investing further research resources in the development of the other benefit categories, A serious effort should be made to implement empirically the Rosen (1974) and Freeman (1974) estimation procedure in a single coordinated research project, in order to obtain national estimates of the benefits of air pollution control.

2. Household Production Function

There is a common perception that the reduction of health effects constitutes, both absolutely and at the margin, the greatest benefit of air pollution control. Substantive opportunity to test this perception is now available in the form of an analytical framework commonly known as the household production function.

Fundamentally, this approach views the consumer as combining market-purchased goods and his own resources to produce a state of health; that is, medical services and other remedial and precautionary measures are not desired for their own sake but are instead used because they reduce the probability that certain states of the world will occur or because they reduce the loss to the consumer, given the occurrence of certain states of the world. The properties of these household production functions for states of health can readily be perceived as being determined by the state of the household's consumption technology in precisely the same manner that the properties of conventional production functions of firms are determined by the state of standard production technology. Conceptually, air pollution is thus considered as an exogenous factor that detrimentally influences the state of health likely to be attained with a given mix and magnitude of household inputs.

The household production function approach to the theory of the consumer is consistent with alternative cost, opportunity cost, or willingness-to-pay measures of benefits of air pollution control. The alternative cost measure, for example, requires investigation of the ways in which the consumer can, under given ambient air pollution conditions, combine market-purchased goods and services as well as his own resources to produce a particular state of health. Development of opportunity cost or willingness-to-pay measures would, of course, require that the consumer's choice process among alternative states of health be accounted for. The theoretical development of these latter two measures within the household production function framework is set forth in Rosen (1974). Evidence is abundant that empirically sound opportunity cost and willingness-to-pay measures can be obtained via the approach for such nonmarket activities as church attendance, human fertility, other things, tion, outdoor recreation, medical services, and a variety of other topics.

Previous studies of the economic benefits of reducing the health effects of air pollution neglect, among other things, the value of the leisure time the individual loses while he is ill, and fail to account for individuals who are nonparticipants in the work force or who refuse medical services. Moreover, these studies do not recognize that the consumer may be uncertain about the covariation of air pollution and health effects and about the "productivity" of particular precautionary or remedial activities, Finally, previous studies have abstracted from the possibility of the individual learning about effects and about the productivity of various activities as well as the possibility that he eventually becomes acclimatized to air pollution and thus attaches less relative importance to its presence.

The major advantage of the household production approach is that it provides an analytical framework for the resolution of the issues cited above. U.S. EPA should encourage research efforts that attempt to establish in detail the empirical observations required to gain the necessary insights from the analytical perspective of household production functions.

3. Input Productivity Studies

Past studies of the economic effects of air pollution on production inputs have focused entirely on specific inputs without giving attention to the manner in which these inputs are involved in a production process. This is due to the universal absence in these studies of an explicit model of producer behavior. Moreover, these studies have dealt with non-human inputs (e.g., materials damages). The economics of the effects, of air pollution upon the supply of worker effort and participation has apparently not been studied at all.

The analytical perspective that studies of this sort might adopt is exemplified at least in part by the perspective this author is employing in a U.S. EPA-funded study of the impact of air pollution upon the work performance of citrus pickers in southern California. In this study, the individual citrus picker is viewed as a contractor who sells his labor services in response to various combinations of piece-work wage rate offers and expected picking and environmental conditions. The product the picker is selling is the number of boxes of fruit he picks within a given time interval. His returns are determined by his wage per box of fruit picked and the relative ease of picking the fruit. It is thus presumed that the worker attaches utility to his working conditions as well as his additional income and is willing to substitute one for the other. The grove owner is aware of this. He thus produces a primary output (fruit) that he sells in the market and a set of working conditions that he offers his pickers. The grower's problem is then to choose a combination of working conditions and fruit output, while the picker's problem is to choose a combination of working conditions and piece-work wage rates.

This analytical perspective coincides with the fundamental view of voluntary coordinated production presented in Thompson (1968), Alchian and Demsetz (1972), and Cracker (1973). It can be empirically implemented by means of procedures similar to those set forth in Rosen (1974). It seems desirable to invest some research effort in additional attempts to assess these effects, because there is no existing information dealing with the impact of air pollution upon labor supply and productivity, because an analytical framework and empirical observations are readily available, and because it is not implausible that the effects in question may be substantial. It is likely that the analytical framework and perhaps some of the empirical results will be transferable to labor productivity situations involving other environmental pollutants in the work place.

4. Environmental Quality Indices

In the early 1970's, there was some hope that useful indices could be constructed capable of conveying in capsule form some information about changes in benefits of improvements in environmental quality. Enthusiasm for the possibilities of constructing these indices was evident in the 1972 Annual Report of the Council on Environmental Quality, though subsequent reports have been noticeably less sanguine about these prospects.

Attempts to construct such indices have viewed changes in ambient pollutant concentrations as being nearly synonymous with changes in air pollution control benefits. Factors indicative of social valuations have entered only as more-or-less arbitrarily chosen weights to be attached to the changes in ambient concentrations of each pollutant of concern. These weights were typically based upon the Federal primary or secondary air quality standards, and a great many facets of the economic benefits of air pollution control were neglected.

To improve upon earlier attempts to construct useful indices of changes in the benefits of air pollution control, one needs to initiate the exercise from within an analytical economic framework rather than a physical taxonomy. In particular, the quality of the atmosphere must be viewed as a factor of production that, in combination with other factors, influences objects such as states of health that individuals value. Thus, for example, one aspect of the "quality" index of an urban atmosphere might be the difference in some morbidity characteristic in the present relative to some predetermined standard atmosphere.

Even if dollar values cannot always be attached to the particular object of preference, a great deal more information about benefits would be conveyed in this manner than with a simplistic recitation of ambient pollutant concentrations. Moreover, in order to construct a useful index, one need not have near-complete information on the relation connecting air pollution to the object of preference. In many cases, the accumulated wisdom and knowledge of researchers will permit the assignment of probabilities to various possible forms af the relation.. These probabilities can then be aggregated to form the desired index, in accordance with well-known principles of the mathematical theory of probability.

5. Form of Benefit Functions

Economic theory provides few clues to the functional forms appropriate to the specification of economic relationships. Benefit functions have been estimated using a variety of specifications without noticeable concern as to the appropriateness of the functional form chosen. However, the choice of specifications affects one's estimates of the characteristics of the benefits function and therefore the calculated benefits from a change in ambient air pollutant levels: This has been recognized by Nelson (1975) in his employment of the household production function approach. Recent references on the problem of choosing functional forms include Dhrymes *et al*. (1972), Pesaren (1974), Ramsey (1974) , and Schmidt (1974).

6. Interview Studies

The major reason for distrust of interview studies in which the interviewee is asked his willingness to pay for alternative ambient air quality states is that he has an incentive to bias his responses depending on how he anticipates the information will be used. Although statements of total willingness to pay for given levels of air pollution control may be biased, the differences in total willingnesses to pay for various levels may be reasonably accurate representations of marginal willingnesses to pay. It is, of course, the latter that is of primary importance for decision making purposes.

It is difficult to conceive of any way other than interview studies of valuing such amorphous facets of air pollution problems as visibility and other aesthetic effects (Randall _et al._, 1974; Krutilla and Fisher, 1974). Moreover, certain techniques for eliciting truthful responses about preference orderings have recently been developed by economists studying the demand for public goods (Clarke, 1971; Bohm, 1972). Although most of these techniques have not been empirically implemented, it seems worthwhile to study their. possible empirical biases in some detail, if only to ascertain whether the present state-of-the-art really justifies the continued viewing with great skepticism of interview studies.

7. Studies of Agricultural Damages

Studies of air pollution damages to agricultural crops have focused upon the physical response, i.e., the influence of air pollution upon the physical magnitude of output and the mixes and magnitudes of physical inputs that are adopted. The calculated economic damages reported in agricultural damage studies typically assume that changes in these outputs and inputs have no influence whatsoever upon the unit price of the output or the unit costs of the inputs. The determination of these price effects requires the construction of a detailed econometric model of the agricultural market in question. Models of agricultural markets that are capable of capturing these price effects are generally available, and should be applied to air pollution studies.

8. Testing for Exclusion of Variables

Many of the investigators of property value and health effects studies have had to rummage through large data files involving numbers of structural, neighborhood, household, and personal attributes that, given the discriminatory abilities of the models employed, could plausibly be determinants of property values or health effects. Generally, no prestated strategy performed in a reproducible way has been used to choose the set of explanatory variables for which estimated parameters are finally reported. This is true in spite of the widely known fact that the exclusion of a relevant variable from an expression to be estimated will usually bias the estimated parameters of the included variables.

In order to ameliorate this problem, some writers have employed factor analysis, However, the economic meaning of the grouped variable then obtained is typically unknown. A program called AID (Automatic Interaction Detector) by Sonquist et al. (1973) simulates the prestated, if complex, strategy followed by a good researcher in searching for the explanatory variables that increase his power to account for the variance of a dependent variable. Using this program, it should be possible to substantially reduce the likelihood that a relevant explanatory variable is inadvertently excluded while simultaneously avoiding the construction of economically meaningless grouped variables.

E. STATUS AND PROSPECTS OF BENEFITS ASSESSMENT

This closing section reviews the current state of the art in assessment of air pollution control benefits and weighs its role and prospects in policy decisions. An increased allocation of resources is advocated.for implementation of a directed and meaningful research program..

1. Status and Role of Benefits Assessment

In my opinion, the current state-of-the-art in assessment of the benefits of air pollution control is rather feeble. Entire classes of benefits possibilities stemming from amelioration of uncertainty and inter-temporal externalities are nearly completely neglected on both analytical and empirical terms. Static, nonpecuniary externalities have monopolized empirical attention. However, the results from studies devoted to this class of benefits have rarely been stated in a form most useful to the decision maker. That is, no probabilities have been attached to the alternative results. Because of the frequent absence of an explicit analytical framework grounded in economic theory, the economic meaning of many of these results is a matter of guesswork in any case. Given these problems, attempts to establish aggregate national estimates of the benefits of air pollution control are subject to enormous error.

The prospects for attaining national damage estimates are by no means entirely bleak, however. New analytical approaches and empirical techniques have become available that are soundly based in economic theory, are susceptible to empirical treatment, and for which data are already available or at least are readily collected. The application of these approaches and the empirical techniques necessary for their implementation for estimation of the benefits of air pollution control is feasible. Moreover, from the perspective of decision makers, the encouragement of these approaches and techniques should be worthwhile and is likely to become increasingly so.

It is axiomatic that the set of obligations faced by a public decision maker will usually differ greatly from the obligations faced by the sufferers from and perpetrators of air pollution, if only because the public decision maker is unable to appropriate directly any pecuniary benefits his decisions may cause. Thus the benefits of one activity relative to another will differ between the public decision maker and the air pollution sufferers and perpetrators. Therefore, if the public decision maker is to act as the embodiment of the sufferers and perpetrators by choosing the set of activities maximizing the combined value of the air resource to sufferers and perpetrators, it must itself face a price structure, given its own obligations; that will cause it to choose this set of activities. Use without complementary information of benefits assessments and associated cost assessments (that is the price structures relevant to sufferers and perpetrators) may cause the public decision maker to choose an inefficient set of activities. Nevertheless, benefits assessment can be of great assistance in choosing the set of activities that, given the decision maker's obligations, constitute the economically efficient set of activities. The reasons are several.

First, the availability of sound benefits assessment can help set the decision maker's thinking straight. It makes it more costly for him to set a policy course that entirely neglects the pervasiveness of economic scarcity. Second, it enhances the development of a framework in which, as additional information is accumulated, more sophisticated and knowledgeable analysts can insert their own results and probability estimates to make more informed judgments. Third, it also permits the decision maker to insert his own results and probability estimates about air pollution control benefits. Fourth, it helps the decision maker see which questions for possible further investigation are of greatest impact in terms of changing policy choices. Fifth, if put together in a coherent analysis, it may at least point toward a class of desirable policy decisions and, on occasion, even a unique decision. Finally, the chances of the decision maker erring are likely to increase progressively through time if he disregards benefits assessments in his policy choices.

The last of the above arguments for public decision making giving more attention to benefits assessments rests on two considerations that have received a good deal of attention in the recent economics literature which has been synthesized by Krutilla and Fisher, 1975. The first of these considerations is that for a great number of people man-made environments do not substitute for natural environments over a quite wide range of availability of the latter. This range of nonsubstitutability or very low substitutability appears to increase with respect to realistic increases in per capita incomes. Furthermore, there are strong theoretical grounds for arguing that improvements in man's production technologies tend to enhance the supply of man-made goods and services while leaving the supply of goods and services produced by natural environments either unaffected or causing this supply to decline. The implication is again that the value of natural environments relative to man-made environments will tend to increase over time. A casual approach by public decision makers to benefits assessment can therefore become increasingly costly to the citizenry whose welfare the decision maker is supposed to be enhancing.

2. The U.S. EPA Program

In view of its potentially important role in establishment of environmental policy, one is moved to ask why benefits assessment research has not progressed farther in the recent past and why, if appearances are real, it has now been accorded a rather low research priority by U.S. EPA. Several plausible reasons exist for this state of affairs.

It's possible that skepticism by natural scientists about the discipline of economics has been a factor in U.S. EPA's reluctance to use economic models for benefits assessment while amicably greeting models from biomedicine, meteorology, and other areas that provide estimates with larger errors and greater sensitivity to extreme events than do economic models. Such a situation is unlikely to be ameliorated unless someone who understands economic analysis is provided equal opportunity with natural scientists to formulate U.S. EPA's research programs.

An additional factor that may have contributed to the relative lack of U.S. EPA concern about benefits assessment is the Clean Air Act itself. Of the many objects of preference individuals have, this Act can readily be read as elevating health to a place where little else can be considered in research activities or control policies until the public health is fully protected [see Sections 103(a) and 109 (a)]. Consideration of economic considerations is relegated to vague statements about the public welfare while explicit reference to epidemiology, toxicology, etc. is made. The desirability of the vague statements and the explicit references is not at issue. The point is that the Act is probably interpreted as saying that economic considerations are, at best, of secondary importance in air pollution problems.

This, of course, is not true, for the Act nowhere inhibits economic considerations with respect to whether to set, for example, an ambient standard or a source performance standard, or whether or not to set <u>any</u> standard whatsoever. It is here that benefits assessment can be of greatest value to decision makers. Nevertheless, research on the economics of air pollution control benefits has not yet produced a set of results regarded to be sufficiently compelling to warrant their serious use in air pollution control planning.

U.S. EPA appears to have lacked a successful research strategy in the economics of air pollution control benefits. The two main features of any existing strategy seem to have had speed of acquisition of results and accumulation of piecemeal, uncoordinated, isolated studies by individual researchers. The first of these features implies a failure to recognize that any serious analytical effort takes a fair amount of time and that crash programs are not likely to be successful. As someone has pointed out, a crash research program bears at least a family resemblance to an effort to have a baby born in one month by getting nine women pregnant. U.S. EPA's efforts in biomedical and technological research have perhaps followed more normal and acceptable fertilization procedures.

The result of the piecemeal feature has meant that a random collection of studies, highly variable in quality and significance, has been produced. These isolated efforts do not serve effectively as building blocks to be put together in a cumulative fashion for subsequent studies, nor are they particularly useful for decision making purposes.

In fact, such an effort can fruitfully be viewed as an investment-production process characterized by considerable uncertainty and stochastic elements (i.e., surprises, disappointments, and errors). Naturally, in this investment-production process, as high a return as possible is desired. However, that which constitutes a payoff and the means by which this payoff is to be maximized, cannot be adequately characterized, without knowing the objectives of those who will use any information that is generated. Otherwise, one can't know whether the research emphasis given various regions, pollutants, sufferer classes, and analytical and empirical refinements correspond to those most useful to decision makers.

In the absence of knowledge of explicit objectives, my major research recommendation is that the U.S. EPA concern with aggregate national control benefits should, for the moment, be limited to development of a plan for microeconomic benefits research that is explicitly tied to economic theory and which will permit consistent aggregation within a framework accounting for the intrinsic uncertainty of all benefits estimates. My views as to what constitutes the possibly effective long- and short-term components of this strategy have been set forth earlier in this paper.

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ATTACHMENT. AN ILLUSTRATION OF SOME ISSUES IN BENEFITS ASSESSMENT

This attachment seeks to illustrate the application of the foregoing discussion to a real world problem by analyzing the benefits accruing from controlling a single class of pollutants in a specific locality.

1. Introduction

Conventional microeconomic theory constructs an extremely general conceptualization of the consumer or producer decision making process. For example, in the case of the consumer, households are assumed to allocate their budgets so as to maximize the utility they derive from the purchase and consumption of goods and services subject to the constraints imposed by the resources to which they have access as well as the prices of the commodities available to them. Since the conceptualization is extremely general and, therefore,abstract, many issues that are of importance to particular applications are assumed to be irrelevant in order to focus attention on the key principles governing consumer choice.

However, once the framework is applied to a specific set of decisions, such as those involving the behavior of sufferers from air pollution, then an array of details must be reviewed. These details are indeed relevant to the usefulness of the models on which the decisions are to be based and to the behavioral outcomes that these models would predict. Inclusion of these details considerably complicates the analytic, and even more the econometric treatment of the benefits of air pollution control; but outright omission in the interests of tractability may grossly misrepresent the phenomena involved. By focusing upon a particular type of market in an identifiable locale, the reader should become more sensitive to the most important of the aforementioned details and the difficulties one faces in trying to account for them.

The natural framework of analysis for the economist is the market, the interaction of buyers and sellers. Air pollution affects behavior in a wide variety of markets, each of which has its own unique structure. As used here, the term "markets" is meant to apply to all air pollution control benefits studies employing market-established prices or some surrogate as a means of establishing benefit assessments. The term is thus meant to encompass each of the methods of assessment (technical coefficients, market, opinion surveys, litegation, political expressions, and Delphi) that Waddell (1974) distinguished. The presumption is that a model, whether implicit or explicit, of a market is present when any one of these methods is employed in a given situation. That is, at its roots, any use of one of these methods involves some perspective of the structure of buyer and seller interaction.

The benefits of air pollution control in the particular market to be discussed are probably trivial relative to the benefits in markets such as human health and life, materials, housing, and assorted other buyer and seller interactions in which air pollution is thought to have a significant role. Nevertheless, this case is very illustrative for each of its peculiarities are present in one or more of the markets that are typically studied for purposes of estimating the benefits of air pollution control. In addition, this case illustrates the difficulties encountered in analyzing the recreation benefits of water pollution control which have been mentioned in the other papers of the report. Recreation benefits are, it is frequently asserted, a major portion of the total. benefits of water pollution control.

2. Presentation of the Problem

The San Bernardino Mountains of Southern California serve as one of the primary outdoor recreational resources available to the approximately 11 million people of the Los Angeles Basin. On the slopes of these frequently extremely steep mountains grows a highly varied set of plant communities ranging from hot desert to sub-artic. The lower portions are dominated by a fairly dense coniferous forest consisting primarily of ponderosa pine and white fir. Here are found the most heavily used outdoor recreational facilities, including hiking trails, campgrounds, lakes, small mostly intermittent streams, and arrays of publicly and privately provided outdoor recreational amenities, such as cabins and restaurants.

Most users of these facilities would probably agree that the ponderosa pine, an esthetically pleasing tree that is large, tall, shady, and straight-stemmed, contributes significantly to their outdoor recreational experiences. Recently, however, a relation has been found between ozone, or ambient oxidants, and susceptibility of this pine to attack by insects. It is thought that the combined action of insects and pollutants results in higher rates of needle drop and death than the action of insects alone. (Miller et al., 1968; Stark et al., 1968; Cobb and Stark, 1970).

Let us presume that the biological relationship between photochemical oxidants and ponderosa pine morbidity and mortality has been reasonably well established. The problem facing the economist, then, is to tie to this biological relation a welfare measure that simultaneously registers the values of outdoor recreationists and is meaningful to air pollution control decision makers. That is, the economist's task is to assess the value outdoor recreationists place upon the presence of healthy ponderosa pine.

This task is not easy, since neither air pollution control, the services of ponderosa pine forests to outdoor recreation experiences, nor recreation experiences themselves are, for the most part, exchanged in organized, explicit markets permitting direct observation of the relative values households attach to such goods and services. One must therefore infer the relative values households attach to ponderosa pine in various states of health from observations on the rates at which these households voluntarily substitute one state for another and the market values of the resources they expend in performing these substitutions.

However, in order to make these inferences, all other factors that influence the voluntary rate of substitution must be accounted for. This accounting requires the construction of a model of the nature of buyer and seller interaction in outdoor recreation. Some of the structural features of the outdoor recreational market that, ideally, should be integrated into this model are described below. With a bit of reflection, the reader will recognize that similar features (in kind, if not in degree) are to be found in many of the actual markets studied in the past to ascertain the benefits of air pollution control. For example, whenever the term "outdoor recreation" appears, the term "housing" or "state of health" would generally serve just as well. (Vars and Sorenson, 1975).

3. Multi-Dimensional Heterogeneity

The sites a household considers in planning its outdoor recreational activities are heterogeneous rather than homogeneous. That is, they exhibit great differences in a number of different dimensions to which the household typically attaches value. Differences in the physical recreation sites themselves are obvious enough. For example, these differences may be manifested in size, number of campsites, topography, forest type and condition, and other attributes.

But an outdoor recreational site embodies more than the physical site itself. It is a composite consisting of the site and its accessibility with respect to alternative recreational sites and the household's residence. Accessibility of sites differs greatly in terms of the pecuniary and temporal outlays required and in terms of the quality of transport mode and route. Moreover, outdoor recreational sites, as well as the transport modes and routes that provide access differ greatly in the cultural backgrounds of the people who frequent them, the assortment of privately owned goods available, the quality and quantity of common property and publicly owned goods provided, and congestion.

The state of affairs described above is really not altogether unusual in applied economic analysis. Just about any entity a household values can be viewed as a composite of several attributes. Frequently, these components will differ substantially among various sellers and among various buyers. Economists nevertheless habitually aggregate these heterogeneous entities into units of analysis they term goods, industries, etc. The aggregate unit of analysis is usually probably a good approximation of the most informative unit for the purpose at hand. However, in the economic analysis of outdoor recreation markets, the question of the most informative units of anlaysis must be approached with a good deal more caution than is customary. The reasons are several.

First, at least to the casual observer, households appear to exhibit great differences in the utility they derive from outdoor recreation. They differ greatly in the value they attach to any form whatsoever of outdoor recreation, as well as in the relative importance they associate with various forms of outdoor recreation. In addition, for any particular form (e.g., viewing scenery), they differ in their preferences for the various components of the form. All this implies that the differences observed among outdoor recreational sites influence the market. To some extent, particularly in the case of accessibility, the observed differences might not be matters of chance but are instead demand-induced.

Second, the consumer and the producer are able to exercise much less discretion as to the components of the commodity in the case of outdoor recreation. The household that consumes outdoor recreation experiences has substantial discretion with respect to the set of alternative recreational opportunities, but, once the choice is made, many subsequent events are outside its control. For example, when arriving in the mountains, the household is unable to control the congestion at a site it does not own. Therefore, it is unable to control the extent of deterioration in the quality of services it had expected to obtain at the site. Since this can greatly affect the utility of recreation and typically occurs without the direct intermediation of the market, there exists a large potential for substantial externalities in outdoor recreational markets.

Third, from the perspective of the individual household, the great variety of outdoor recreational sites available in Southern California means that they are imperfect substitutes for one another. Any fairly large collection of sites is likely to exhibit a range of substitutive relations extending from rather close to nonexistent. Is the beach a close substitute for the mountains? In addition, given the near impossibility of untying the packages into which the components of most sites are bound and, given the limited number of sites the household is likely to consider, there may exist a major difference in the degree of substitutability that pairs of households assign to the same pair of sites. This implies that a single outdoor recreation market does not exist. Instead, there seems to be a set of markets that are more or less related to one another.

One serious consequence of this market segmentation is that the supply and demand relations that constitute each market segment can behave in different fashions across segments. Price elasticity of demand for a particular activity may be high in one segment and low in another; one segment may have excess demand for a certain activity, while another may have excess supply. All this implies that prices, whether implicit or explicit, may vary across the segments. Moreover, an exogenous change that impacts forecefully on one segment may have no impact whatsoever in another segment.

This segmentation of the outdoor recreation market is nourished by the high cost for households of information about market conditions. Information is clearly an important factor in household decisions when one recognizes the great variety of outdoor recreational opportunities and the differences in preferences among households for these opportunities. However, it seems unlikely that households can afford to survey all or even a major part of their potential opportunities. Instead, they limit their search to some portion, a delineation probably based on various rules of thumb reflecting prevailing knowledge about opportunities that are good substitutes for one another.

4. Costs of Market Participation

To a perhaps greater extent than for many other commodities, the act of participation in the various segments of the outdoor recreation market is costly. For several reasons, the cost of the act of participation tends to harden the discrepancies in prices across market segments. First, as previously noted, since heterogeneity in available outdoor recreational opportunities is pervasive and considerable and tastes regarding these differences are quite important, substantial search by a household may be required to assure a satisfactory recreational experience.

Second, the consumption of outdoor recreation generally requires that the household remove itself from its permanent residence and selectively travel to one or more sites at which the chosen combination of the components of the recreation package afe thought to exist. Outdoor recreation does not have the portability of the typical commodity. Since the commodity cannot be carried from one location to another, the household experiences pecuniary and temporal costs in overcoming the distance necessary to match household to site. Third, even after the household's search has been terminated and the distance to the site overcome, actual participation usually requires the purchase of complementary inputs.

These costs imply that the prospective gains from becoming an active participant in the market may have to be quite substantial in order to warrant such participation. The values of those who do not participate are not registered in the market. The prospective gains the household perceives from participation can arise from changes in the household's preferences with respect to different combinations of outdoor recreation packages and with respect to recreational versus non-recreational commodities. They can also arise from changes in the components and in the implicit and explicit prices of the different packages available on the market.

Barring changes of these sorts, the high cost of market participation suggests that participation is likely to be intermittent rather than continuous for most households. This, in turn, implies that the set of households one observes participating, and thus determining the outcome of market transactions in any fairly short time period, might not be representative of the entire population of households.

5. Institutional and Temporal Constraints

Apart from the problems that multi-dimensional heterogeneity, information, and the costs of market participation introduce, the outdoor recreational market bears little semblance to a perfectly free market. Indeed, the outdoor recreational market in Southern California has been subjected to a number of public institutional controls, including assorted health and safety regulation, non-price rationing, such as queuing, and zoning regulations intended to inhibit congestion. In effect, these controls reduce the domain over which the market is able to exercise discretion in adjusting to changing situations.

Although the reductions in negative externalities which these controls permit may well exceed any losses in efficiency which the controls engender, such losses are nevertheless undoubtedly present.

They involve the losses present when every household is forced to consume and/or produce in more or less the same manner and the flexibility that is lost when the only parameter subject to occasional adjustment is the value of the regulation. Moreover, to the extent they reduce substitutability among sites, the controls intensify whatever tendency toward market segmentation already exists.

The constraints the household faces while recreating are not only budgetary and those publicly designed to shape its activities. Most households are unable to allocate their time in any arbitrarily desired way. Instead, the household's free time for outdoor recreation is structured and limited by inalterable work schedules. In the case of family units, work and education schedules may interact, so as to curtail family recreational time futther. Even individuals who are self-employed are constrained to the extent they must interact with other individuals and businesses.

6. Conclusion

All of the issues discussed above are relevant to the assessment of effects that changes in the health state of the ponderosa pine forest have upon the choice behavior of outdoor recreationists in Southern California. The discussion is, in fact, germane to most, if not all, markets that are studied to assess the benefits of air pollution control. Nevertheless, a model capable of capturing the full impact of the multi-dimensional heterogeneity, cost of information and market participation, and institutional and temporal constraints of the outdoor recreation market upon the household's decision problem would indeed be unusual. In any model that is to have real application, the treatment of many and sometimes most of the issues raised above must of necessity be conjectural. That is, in his applications of a model of beneficiary behavior, the investigator must be willing to take a subset of these issues as already settled for the application in question. Both the limited availability of suitable data and the limited abilities of investigators in model construction dictate the failure to comprehend in each instance the range of these issues.

Most fundamentally, in any attempt at benefit assessment one must examine the role the assessment is to have in the decision making process. In effect, one must know with some precision the criteria to be used to evaluate the assessment as well as the objectives of the assessment effort. Such knowledge permits the investigator to isolate those facets and issues with significant implications for decisions from the less important ones. (Crocker, 1975).

IV. BENEFITS OF WATER POLLUTION CONTROL

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A. INTRODUCTION

Despite the richness of the literature in applied welfare economics and benefit-cost analysis, there is currently very little concrete knowledge of the extent of economic benefit which would result if water quality were brought up to state and Federal standards. The development of what knowledge does exist has been very asymmetric. Estimates of production losses, including conventional waterborne disease, are reasonably firm; unfortunately, only a small fraction of the potential benefits appear to be in these areas. The predominant share of the potential benefits appear to be in the categories of recreation, aesthetic uses, and option demands, where the methodologies for simulating consumers' willingness to pay for quality improvements are much less well developed.

The lack of adequate, generalizable behavioral relationships between water quality and consumer behavior, and hence, willingness to pay for quality improvements, is thus the predominant problem in assessing pollution control benefits. There is simply inadequate knowledge concerning why people "consume" leisure-type environmental activities, and especially how changes in water quality (objective and/or perceived) affect these consumption activities. Some creditable work has been done in estimating recreation benefits from pollution control in small areas, but extrapolation of these studies to national aggregates is not currently possible with any degree of precision. The monetization of aesthetic and option demand is, at present, even less well developed than for active recreation uses.

Increased precision in the measurement of consumption benefits (recreation, aesthetics, option demand) will come slowly and probably fortuitously in the absence of an expanded U.S. EPA role in benefit estimation. This is particularly true for the evaluation of efficiency at an aggregate level. decentralized academic researchers do not have an incentive system which encourages them to derive "premature" estimates of national benefits <u>or</u> to structure their partial equilibria analyses to facilitate this derivation by U.S. EPA or other institutions. Asking even the best consulting firm to extrapolate existing partial analyses when these were not designed to be extrapolated is a hopeless strategy.

Thus, U.S. EPA should assume an expanded role in designing and funding high-quality analyses of consumption benefits, where these analyses have the express objective of being extrapolated to national levels. As a complement to this activity, a basic commitment should be made by EPA to establish a long-term "behavioral monitoring system" analogous to that established by the U.S. Geological Survey for assessing water quality. Common socio-economic and physical data sets need to be maintained over time at sites where water quality changes are, in fact, occurring. The rationale is that a much more adequate knowledge of behavioral response with respect to water quality changes must be established before the efficiency of water quality enhancement can be assessed with any substantial precision.

B. CONCEPTUAL FOUNDATIONS

This section is intended only as an overview of the welfare economic foundations of benefit estimation in water pollution control, since several other sources treat this essential topic in much more detail. It identifies and synthesizes the implications of general and specific problems affecting current benefit estimates, by category of damage (e.g., health, recreation), and offers a set of suggestions for improving the quality of future estimated.

1. Role of Benefit-Cost Analysis

Historically, benefit-cost analysis has been a valuable tool for analyzing the economic worthwhileness of alternative public policies. Although its origin can be traced to legislative mandates (e.g., the Flood Control Act of 1936), rather than theoretical modeling, substantial theoretical and empirical literature on benefit-cost analysis now exists. The relevance of this literature to the analysis of benefits and costs of water pollution policy has been documented in a 1973 EPA Symposium, the proceedings of which are now in print and available to administrators and researchers (Peskin and Seskin, 1975).

A particular policy can be supported by two antagonists, each of whom views the policy as contributing to a different objective. Also, it is uncommon in the political world that the real objectives of the policy's promoters will be explicitly stated, if in fact, the promoters are actually capable of articulating these objectives. Indeed, the "muddling through" or "disjointed incremental" approach to public policy (Lindblom, 1959) rests largely on the notion that agreement on "means" (i.e., policies) is primary, and that agreement on "ends" (i.e., objectives) is secondary and perhaps even unnecessary.

Benefit-cost analysis, on the other hand, presupposes that objectives do matter in the public policy process. Simply stated, the benefit-cost analyst says: "If X (or Y or Z) is your objective, then that particular objective is enhanced (or impeded) by the policy or program under consideration." The variety of objectives to which benefit-cost analysis can be addressed is limited, yet the tools are powerful if economic efficiency is a relevant objective.

Three possible objectives of water pollution control policy are:

- To make efficient use of resources associated with water use
- To distribute goods and services, including those which are water-related, in an "equitable" manner
- To avoid ecological irreversibilities.

Benefit-cost analysis can make a potential contribution to each of these. However, a '"state of the art" assessment of benefits from water quality improvement can most productively be focused on "national efficiency" benefits, or those which would arise from the increased value of goods and services made possible by water pollution policies. Economic science is far more advanced in contributing to this objective than to the two other objectives.

Differential incidence of benefits and costs among various people or groups may arise from different water pollution policies, and decision makers may choose to look at the problem partially or solely in this context. The state of economic science at present is inadequate to define distributional benefits in a normative sense, but instead is limited to a positive description of "who gains," "who loses," and "how much." Such descriptions are inherently useful, and should be included in any assessment of pollution control benefits and/or costs. Finally, benefit-cost analysis may be used to identify the costs of maintaining a designated water quality standard, even though the benefits from maintaining this standard may not be fully quantifiable or even perceived at this time (Krutilla, 1967).

2. Estimation of Benefits

Efficiency benefits should be defined in terms of the total value to users of increases in the national output of goods and services, where total value is defined in terms of willingness of users to pay for the additional output. Because it is often not feasible to measure individual demand functions, and hence, the willingness to pay by users, four alternative techniques for assessing these benefits have been devised.

If markets for the goods and services exist, and if the additional output does not have a significant effect on price, then market prices can be used to assess benefits. This technique will be of little value in assessing water pollution control benefits, since markets are seldom used directly to determine water quantities or qualities. Simulated markets, including demand functions, supply functions, and/or simulated market outcomes, can be used as a proxy for real markets. While the methodology for this technique is rudimentary in its development, it appears to be the only relevant technique for evaluating water quality benefits where outputs are "consumed" directly by final users. In particular, benefits to recreation and aesthetics will need to be evaluated by this method.

If the output of investment is an intermediate good, rather than one intended for final consumption, then changes in the net income of producers (or consumers), with and without pollution, may be used to reflect benefits. This method will be useful primarily for determining benefits from controlling industrial and agricultural pollution, and from reduced waterborne disease. Finally, if computation of net income changes is not feasible, the cost of the most likely alternative for attaining the same objective can be used to measure benefits. The rationale behind this method is that benefits are obtained to the extent that resources are thereby released for the creation of other goods and services.

A second category of benefits, often termed "secondary benefits," are those which might result from the use of resources which would otherwise be unemployed or underemployed (Haveman and Krutilla, 1968). In general, one would not expect to find substantially improved employment opportunities for otherwise underemployed resources, if national water quality were restored to meet Federal and state standards. The reason for this expectation is that water pollution has probably occurred gradually enough that the market has had time to re-allocate resources away from polluted areas.

3. Special Considerations

If market data could be relied on extensively for calculating benefits, care would need to be exercised to see that the markets were competitive and to account for project-induced changes in price. Under such circumstances, welfare economic theory provides a basis for asserting that prices reflect social values, provided that one accepts the prevailing income distribution as "proper". In the case of water pollution, however, much reliance in benefit evaluation must be placed on simulation of markets for non-market goods such as outdoor recreation, and calculation of net income changes. Therefore, special attention would need to be given to several criteria which relate to the internal consistency of the analysis.

Thus, inferences as to technical relationships should be at the highest "state of the art" possible within the relevant discipline. For example, the nature and extent of man-made pollution should be identified, along with marginal treatment costs for these pollutants. To the extent feasible, inferences of technical relationships should be both complete (e.g., no major omissions in types of waterborne diseases) and capable of replication.

Although direct market prices for goods and services produced by water pollution control will be of limited value in the direct assessment of benefits, some reliance must of necessity be placed on real or synthesized price data in the simulation of markets for certain goods and services. Examples include:

- Health
  - cost of medical treatment
  - value of time lost to illness
  - value of human life (present value of future earnings)
- Outdoor Recreation
  - costs of vehicle operation and travel
  - value of time spent in travel
- Production
  - marginal costs of waste treatment for various types and levels of effluents.

Use of price data where market prices are artifically set, either by imperfect competition or through public policy, should theoretically be discouraged. This is easier said than done, when one considers this varied range of contrived market outcomes:

- Health
  - restricted supply of medical personnel
- Recreation
  - OPEC policy on U.S. oil imports
  - auto prices administered by U.S. manufacturers

- Production
  - degree of price competition among suppliers of pollution control equipment
  - price support levels of farm crops lost to siltation and brackish water.

About the only reasonable expectation is that the analyst be able to identify major price imperfections where knowledge of such has been documented (e.g., farm price supports).

Where price data are relevant in the synthesis of proxies for "willingness to pay," the expected level of such prices over the lifetime of the project needs to be identified. Use of current prices such as, for example, the current cost of travel, may lead to inflated or deflated estimates of benefits, depending on what constitutes a "reasonable" long-term price expectation.

To the extent possible, the analyst should identify significant technological externalities which would be alleviated by expanded policies of water pollution control. In fact, this should form the substance of benefit calculations for improvements in water quality; these improvements would reduce the level of negative externalities to users (e.g., disease, degraded recreation opportunities). National efficiency benefits, regardless of method of calculation, should be net of pecuniary externalities (income transfers). Especially if the "net income" approach is used in benefit calculations, care should be taken that offsetting income losses are included in the analysis. Also to be questioned or excluded are windfall net rents which may accrue to fixed assets without corresponding increases in outputs of goods and services.

Where the investment project for augmenting water quality levels is expected to produce benefits extending over several years, the annual increment (or decrement) to benefits should be identified, and the present value of current and future benefit streams should be computed. Goods and services provided directly to consumers through water quality restoration are of particular concern here, in that the income elasticity of demand for different services may vary widely.

With respect to human health, research indicates that the value of the human agent has risen markedly over time (Schultz, 1968). So,too, has the demand for services to maintain the human agent, including health services. One would suspect a high and rising income elasticity, then, for avoidance of waterborne diseases. Within the category of outdoor recreation, there is reason to suspect that a substantial range exists in the income elasticities for different activities, including some "inferior" goods (Stevens, 1966). Conceptually this poses a weighting problem for assessment of benefits at the national level, where annual changes in benefits are a function of the composition of current-year benefits (by recreation activity), the expected income growth in the economy, and the income elasticities of the different activities.

These time-related changes should be identified in computing annual benefit streams. Inclusion of such calculations and breakdown of the requisite investment into installation cost and operating cost components would improve both the benefit and cost estimates, since investment projects for improving water quality would be capital-intensive and long-lived in nature.

C. GENERAL PROBLEMS

This and the following section are meant to be synoptic statements on the state-of-the-art, rather than a detailed review of empirical studies on benefit estimation.

State of Damage Functions

The most complete and useful review of empirical attempts to estimate water pollution control benefits is Tihansky's chapter in Peskin and Seskin (1975). To quote selectively from his conclusions: "This paper reviews an extensive compilation of major benefit studies. From an original collection of almost two hundred studies, approximately sixty are selected as contributing most to the conceptual framework and empirical insights of benefit evaluation. Of the selected studies, less than 30 percent are theoretically valid, but even fewer seem cognizant of the applicability, let alone the existence, of welfare economics . . . If only recreational studies are considered, fewer than 10 percent follow from theory . . . Although there is no theoretical basis for most benefit values, equally discouraging is the paucity of empirically derived damage functions. Only 20 percent of the surveyed literature derives dose-response relations from on-site data. With recreation studies, this proportion decreases to 10 percent."

Despite some allegations to the contrary, water quality data are relatively abundant. The real problem, however, is the lack of conceptually valid functional relationships between water quality parameters and associated human behavior. We need to know:

- How economic activity affects the nature and concentration of waterborne pollutants
- How the latter affects behavioral perceptions of water quality
- How this perception is translated into behavioral decisions.

Welfare economics is a useful and integrative conceptual base for benefit estimation, but existing facts often have multiple interpretations since functional relationships well-founded in theory have usually not been established. Generally speaking, welfare economics is a "non-problem" in that the accumulation of theoretical insights has far outrun the empirical implementation of the theory.

The current "state-of-the-art", in assessing water pollution control benefits strongly reflects an asymmetric development in terms of establishing such functional relationships. The reasons are partly economic and partly institutional. At an earlier stage of economic development in the U.S., the primary concern with water quality was for human health and safety. The whole historical thrust of the Public Health Service has to do with developing functional relationships between pollutants and waterborne disease. Especially with the more virulent and contagious diseases, a fairly simple behaviral response was assumed, i.e., avoidance.

As economic development progressed, natural resources were increasingly regarded as items for consumption, rather than production. At an institutional level, the Public Health Service continued to be concerned with the production of health. Elsewhere in government, water-based leisure (and most other forms of recreation) were evidently regarded as something to be done, not studied. Increased awareness of this knowledge gap led to the creation of the Outdoor Recreation Resources Review Commission and subsequent efforts elsewhere in government.

Within this set of poorly understood leisure-type phenomena are those which relate changes in water quality to changes in consumer behavior. In particular, damage functions which relate to active recreational uses of water or to more vaguely defined aesthetic uses have not been established to any substantial degree. Thus, there is inadequate knowledge of the whole set of relationships concerning why people "consume" leisure-type environmental activities, and how real and/or perceived water quality affects these consumption activities. Individual researchers have done creditable work in specifying particular water quality parameters and relating these to particular recreational activities, but there is nothing resembling a comprehensive research effort in this area.

The knowledge which does exist about behavioral responses with respect to changes in water quality is fragmentary. More crucial to the task at hand is that it deals with partial equilibria, i.e., variables which are crucial in the user's decision framework are often assumed as constants in existing analyses. In particular, most of the existing work on recreation benefits assumes a constant level of water quality in bodies of water other than the particular one being researched. In that this group of other sites probably contains some which are substitutes for the one under study, the analytical models are incompletely specified and, hence, less useful than would be desired for purposes of national aggregation. The generation of national benefit estimates implies solutions which are more general with respect to competing sites than is permitted by the current literature.

This is not surprising, in that the immediate objectives of research have usually been to measure costs and benefits of controlling specific water pollutants in specific bodies of water. Ten years ago, when estimation of recreation benefits was in its first primitive stages, it was a real challenge to perform the analysis, let alone worry about extrapolation to higher levels of aggregation. It is still generally acknowledged that consumers have a broader preference set than just the particular river or lake under study. The state-of-the-art is to assume away the influence of competing streams and how recreationists might react to more general water quality changes.

The needed knowledge of behavioral responses to changing water quality levels has not progressed to the point where reasonable extrapolation can be made with any degree of precision. Although estimates of national benefits have been derived in the past (e.g., Unger et al., 1974), these estimates are based on extrapolations which have neither a sound conceptual footing nor an underlying accumulation of coherent empirical work. Tihansky's (1975) review of such studies reveals that the bulk of water quality benefits seem generally to be in those areas where the "state-of-the-art" is least developed, particularly in the areas of recreation, aesthetics, and option demands. The same conclusion is also reached in this present paper.

2. Classification and Aggregation of Benefits

That proportion of specific pollutants which are man-made, rather than naturally occurring, and the approximate control costs for both man-made and natural pollution are often known with some degree of precision. The general tendency has been to impute average (proportional) costs to control of man-made pollutants. However, marginal costs (over and above those required to treat natural pollutants) would be a more appropriate measure. This can lead to overstating the benefits of pollution control.

There is only a weak consistency in the quality of estimates among the various benefit categories. Although health and production benefits are relatively firm, or at least susceptible to refinement through further analysis, this is not the case with consumption benefits (recreation and aesthetics). These estimates must currently rely on highly simplifying assumptions in order to utilize existing research not intended for purposes of extrapolation.

As the "state-of-the-art" develops in benefit estimation, knowledge of the growth rates of benefit streams becomes increasingly important. Technological change in the future is likely to be greater for production activities than for consumption activities. Hence, the costs of pollution to production activities (and hence, potential benefits) may be reduced over time as new technology is developed and implemented to alleviate those problems. Considering health as a "production" activity in a manner consistent with human capital theory, the per unit benefit values may rise over time as the value of human capital rises relative to that of physical capital. Some consumption benefit streams may grow and some may decline, depending in part on the income elasticity of demand for water-based services.

The decision context implicit in an assessment of national benefits and costs is one of aggregate efficiency in water resource use. The broad question is "DO the national benefits of cleaning up our water outweigh the costs?" In reality, the issue of whether or not this is the most productive question to be asked must be faced. Obviously, a good answer to the larger question would be immensely valuable to policy makers.

On the other hand, asking the broad question about an overall benefit-cost ratio may conceal the fact that there are a host of individual benefit-cost ratios (some high, some low) for cleaning up specific pollutants and for cleaning up or protecting specific areas. If the latter is a more appropriate decision context, then criticism of the state-of-the-art has to be mitigated to some degree. Problems with the totality of behavioral responses become less crucial, and a re-focusing on the more pressing responses is facilitated.

3. Other Problems

Even if the question of aggregate efficiency of water quality enhancement could be answered definitively, this would be sufficient information only if policy makers were interested solely in economic efficiency. This is obviously not realistic, as most policy makers are also interested in distributional issues. Whether access to goods and services would be redistributed in a progressive or regressive manner among individuals is information which is almost totally lacking in the benefits literature.

Similarly, pollution control might be progressive, if the costs of pollution, to producers now paid through higher product prices and/or utility rates, were met largely through Federal expenditures financed by a reasonably progressive tax system. On the other hand, pollution control could be regressive if the dominant beneficiaries are white-collar, urban recreationists. In addition, information is also needed on redistribution at a more aggregate level, e.g., urban versus rural states, metropolitan vs. rural areas.

It is crucial that benefits and costs be estimated for a variety of levels of water quality; this is not generally found in the literature. Such a procedure would permit marginal analysis by allowing water quality standards to be viewed as variables, rather than basic parameters to be met at all costs. In light of current concern about the high costs of meeting existing standards, the estimation of benefits and costs for a range of water quality standards becomes very crucial information.

D. SPECIFIC PROBLEMS

This section discusses problems inherent in estimation of specific benefit categories, including health, production, recreation, aesthetic, and ecological benefits, and property values.

1. Health Benefits

It would appear that extensive pre-treatment of drinking water, especially chlorination, has already greatly reduced the incidence of conventional waterborne disease outbreaks, and that further definition of benefits depends on how accurately the following can be quantified:

- Extent of such diseases as hepatitis, gastroenteritis, salmonellosis, and typhoid
- Extent to which these outbreaks can be identified as waterborne, at both current and standard levels of water quality
- Incidence of the outbreaks by morbidity and mortality classifications
- Assignment of unit values, in monetary terms, to the above categories.

Current estimates of benefits in the above categories include 1 billion (Unger, *et al*., 1974), 373 million (Liu, 1970), 356 million (Lackner, 1973), and 120 million (Sokoloski, 1973). While the variation in these estimates appears to be substantial, it is largely due to different working assumptions about facts and functional relationships.

Determination of the real extent of damages from conventional diseases is tractable, requiring additional time and money. Such an allocation is not of high priority, given the softness of the benefit estimates in other categories, particularly recreation and aesthetics. If such an allocation should be deemed desirable, more attention should be given to the following:

- Assignment of mortality values according to human capital theory, i.e., using expected present value of future earnings as the measure of benefit
- Recognition that both the incidence of mortality and expected lifetime earnings are age/sex/race-specific rather than constant over the population
- Recognition that health services are generally income-elastic in demand
- Recognition that costs of medical treatment have risen secularly, as compared to other commodities.

The key problem in quantifying health benefits is how best to deal with uncertain, long-term, and largely unknown water quality-health relationships, such as the presence of carcinogens and certain inorganic compounds in water. Although a consumer's perception of the importance of these events is subject to considerable emotion, misunderstanding, and lack of an informed base from which to make judgments, option value constructs should be explored within this category as well as in the categories of recreation and aesthetics. The reasons for this view are that willingness to pay can arise from desires for future as well as current consumption, option demand can be viewed as willingness to pay for future supplies of a specified good and non-carcinogenic drinking water is surely one such good.

Although it was suggested above that conversion to monetary values be based on a productivity approach (present value of future earnings), an alternative willingness-to-pay framework is now being developed in the literature (Mishan, 1971). An individual's willingness to pay to avoid contracting cancer through drinking water, for example, has an upper bound in terms of his <u>own</u> future productivity, <u>if</u> one makes the value judgment that the individual should be responsible for his own actions and liabilities. On the other hand, society may be willing, explicitly or implicitly, to expand the effective willingness to pay of an individual beyond that which he, himself, would be able to pay (i.e., his future earnings). The possibility of such revealed preferences, i.e., private and public trade-offs between the probability of death and other goods and services, need to be better understood in the context of evaluating serious health hazards with low probabilities.

2. <u>Production Benefits</u>

The principal specific problem within this category is the assumption that the marginal costs of water treatment due to man-made pollutants, and hence the benefits from pollution control, are equal to the prorated portion of the average cost of treatment due to both man-made and natural pollutants. If a substantial amount of natural pollution must be treated in any event, then the marginal costs of treating man-made pollution might be less (substantially or moderately) than average treatment costs. If so, using average cost data would overstate the benefits from pollution control. An extreme case is that of boiler feed water, which is usually demineralized and given tertiary treatment even in the absence of man-made pollutants. In this case, the benefits to reduction of man-made pollutants would be zero, since the marginal treatment costs are zero.

For municipal water supplies, Barker and Kramer (1973) have attributed about 39 percent of total pollution to man-made sources. For damages to household items from water supplies, Tihansky (1973) has estimated that about 17 percent of dissolved solids and hardness are due to man's activities. Also, it has been estimated (U.D. Department of Interior, 1974) that about 40 percent of total salinity in agriculture results from man-made sources.

For agricultural damages due to siltation and salinity, observed prices are often distorted by price supports for farm products. If price supports were to prevent price declines which might result from expanded farm production (due to siltation and salinity control), then use of the price support level to compute benefits would result in overestimation of benefits. This is of particular concern for desert irrigated crops such as cotton grown in the Southwest, where both salinity and siltation are production problems, and where prices are highly influenced by public policy.

3. Recreation Benefits

The inescapable conclusion is that the state-of-the-art is simply inadequate to allow generalizations of existing research to arrive at national benefits. To cite just one example, Unger et al. (1974) derived an estimate of 9.4 billion in recreation benefits from water pollution control. Their estimate involved extrapolation of national values from two small-area studies. One of these involved a high man/water ratio, the other involved a low ratio. Although this was an imaginative approach, the precision with which it can define true national benefits is necessarily undefined, and hence, suspect. The model is inadequately specified with respect to water quality dimensions of the two sites, and the measure of value at either site is not clearly defined.

The above study is symptomatic of the site-situation-specificity of past research on outdoor recreation benefits related to changes in water quality. Whether or not this is viewed as "good" or "bad" depends on one's views of the appropriate decision context, that is, whether or not information on aggregate efficiency of water pollution control is more valuable than information about the relative efficiency of improving water quality in selected bodies of water.

If benefits are to be derived at the national level, research must be sponsored explicitly for that purpose, or one must wait for the decentralized efforts of researchers to produce conceptual frameworks and empirical relationships which can be properly aggregated to the national level. The latter alternative must be viewed as a "long-shot", as the implicit decision context (national efficiency gains and losses) is not one which attracts decentralized research effort when the state-of-the-art is not well developed. The incentive system of most researchers stimulates performance of relatively "safe" projects, such as introducing methodological innovations in analysis of situation-site-specific cases.

Especially relevant for purposes of aggregation is the need for the analyst to consider the entire set of recreational options as perceived by the consumer, and then to analyze how water pollution at one or more sites affects consumption behavior at all sites. Analysis at present (even for small studies) is usually quite partial; no attempt at "netting out" is made. This approach, inherent in small-scale analysis, must be explicitly abandoned in any research attempts to move toward aggregate estimates.

Whether viewed from a perspective of assessing national or local water quality benefits, the principal limitation is the inadequate documentation of a variety of damage functions which relate changes in water quality parameters to changes in consumer behavior. Moreover, in most of the damage functions which have been documented, a key water quality parameter is <u>assumed</u> by the analyst, and its relationship to consumer behavior is derived (e.g., Stevens, 1966). Additional attention needs to be paid to <u>perception</u> of water quality by the recreationist, which may be considerably at odds with the scientist's perception.

Most studies consider only the recreational value of a body of water in its current state, where one or more water quality parameters are not up to standard, and its recreational value if the quality standards were to be met. Such two-point analyses must presume a linearity of value between points, which is probably not valid. For example, bringing the DO levels in a certain river up to 3 ppm might have positive net benefits, whereas at 5 ppm, the incremental costs might far outweigh the benefits. Unless a range of water quality levels is considered, the existing standard is assumed as a parameter, when in fact it might more usefully be considered as a variable.

One area of needed research is the estimation of the income elasticities associated with various water-based activities. Not all leisure or water-based activities have positive income elasticities. One might hypothesize that the income elasticity for swimming in rivers which run through major industrial centers is quite low, and perhaps even negative. In fact, it might further be hypothesized that what appears to be a substantial cost of pollution (i.e., the abandonment of swimming in industrial rivers) is a phenomenon which largely would have occurred in any event through income growth and the substitution of other leisure activities, particularly those which involve travel to less congested and more attractive sites.

If this hypothesis is valid, and it appears tractable to testing, then the implications are substantial. Rather than reclaiming these rivers on efficiency grounds, as assumed in national benefit-cost computations, the reclamation could be justified on distributional grounds (as compensation to those whose incomes do not allow them to recreate elsewhere), and/or to preserve the option to go back to older forms of recreation at some time in the future, is worth the cost, and/or on the basis of "national pride".

The benefits of pollution control can be regarded as the extra travel costs imposed on consumers by water quality constraints which are exogenous to their control. To infer that these benefits from pollution control are the same as what appear to be the damages of pollution may seem valid intuitively, but the symmetry between the two needs to be examined closely.

Unusual income elasticities may cause pollution control benefits to be less or more than the apparent damages of pollution. Recreational preferences are not acquired instantly, and hence are subject to private and public influences, some of which are both strong and pervasive. One such influence is the encouragement of travel through production of both super-highways and super-autos. Hence, there may be substantial lags in returning to urban water-based activities even if all bodies of water were brought back up to standard. Higher energy prices do, of course, pose a constraint to travel, as do the "psychic costs" of driving crowded freeways to escape the crowded city.

One can find micro cases in which the reduction in travel cost would lead to negative benefits. For example, consider two sites of unequal quality, the one farther away being the more desirable. Then if pollution destroys the (more valuable) distant site, the recreationist turns to the less desirable, closer site, and saves travel costs. While this does in fact happen (e.g., in over-use of some high mountain lakes), the model may be appropriate in a macro sense. That is, in terms of absolute magnitudes, water pollution has generally been urban-oriented and people have been forced to travel more, rather than less, to find comparable substitutes.

An ambivalence can be reached on incorporation of the costs of time in recreation benefits in that the opportunity cost of time spent in travel is more likely to be other leisure activities forgone than income generation. To value time at zero, however, might imply that alternative leisure activities are of zero utility; this is not a reasonable argument. It would seem that from an ex ante viewpoint, the expected gains from recreating would at least equal the expected costs, including opportunity costs of forgoing other recreational alternatives, some of which are substitutable with money and, hence, have a positive monetary value.

The net effect of all these considerations is not obvious, and hence, is deserving of research. The conclusion at this point is that the terms "pollution damages" and "pollution control benefits" should not be equated lightly.

A dynamic, simultaneous setting is the reality with which analysts must deal. In this setting, the economy and its system of distribution provides a driving force in re-shaping consumer preference, both through allowing greater discretionary income and in motivating consumers on how and where to spend it. Moreover, economic growth, in part through uncompensated negative externalities, imposes constraints on the range of goods and services which the recreationist can purchase (e.g., "no swimming" signs).

Two conceptual models, presented in Attachments A and B, may be useful in making aggregated assessments of recreation benefits from water pollution control. Model 1 demonstrates the conceptual links between quality, quantity, and price of the recreational experience. Model 2 demonstrates the usefulness of a "reduction in travel cost" construct and specifies data requirements for its implementation.

The typical recreationist finds that water pollution reduces the quality of his recreation experience, causes him to recreate less often, and causes him to incur higher travel costs to enjoy substitute sites. The objective of Model 1 is to demonstrate that these three components (quality, quantity, and price) are conceptually linked, and that addition of the three as separate components is not defensible.

Model 2 (Attachment B) moves toward establishing theory which may be useful in specifying data requirements for assessing national benefits. As a corollary, it may also be useful in interpreting whether or not existing empirical studies and data are of value in attempting to generate estimates of national benefits. The implications of Model 2 are that decreases in travel costs due to pollution abatement represent potential benefits from abatement, existing data on total costs of recreation should be explored as a proxy for travel cost data, and the empirical relationship between pollution levels and travel costs must be established before the model can be implemented empirically.

4. Aesthetic and Ecological Benefits

We have seen that the methodology for simulation of changes in market values for active recreational activities, as a function of changes in water quality, is still being developed and as yet, has not been adequately generalized to a national aggregate. The methodology for monetizing the less active (e.g., viewing) or more latent (e.g., future consumption) uses is even less developed. At present, there is little conceptual or empirical support for any available estimates of national aesthetic benefits from water pollution control.

A specific problem which links the categories of outdoor recreation and aesthetics is whether to believe what people say, or to believe, instead, what they do. Economists have long had a preference for the latter, fearing the lack of appropriate decision context in the former method. In short, people may overstate their willingness to pay if they think it will help secure a good, or they may understate their willingness to pay if they fear that their pocketbooks will somehow be affected. Although economists have long recognized these tendencies, there is relatively little in the literature in the way of constructive analysis on the avoidance of under or overstatement. The work by Bohm (1971) and Tideman (1972) are exceptions, but the reliance on assumption is still substantial there.

The constraint imposed by inadequate methodology is especially apparent when one considers the dilemma that exists where direct questioning appears to be the only available methodology. In the case of option demands on the part of the current non-users, the questioning must be with respect to desire for future consumption. Hence, there is no way to check results of direct questioning against observed behavior. In hypothetical cases of improved water quality, the general question is "What would your recreation preference set be if certain water quality parameters were varied?". In addition to problems that the recreationist might have in visualizing the improvement, there is again the absence of empirical cross-checks.

Despite this apparent dilemma; economists have had little propensity to seek. help from other disciplines. Even in cases where the wording and setting of particular questions are crucial to the results, economists have usually preferred to "go it alone" rather than seek inputs from psychologists, social psychologists , or communication theorists. On the other hand, the non-economic literature on "environmental perception" is flourishing, but usually with no handles by which to impute monetary values.

Analysis of cross-section and time-series data is much preferred to direct questioning, if the data are available. Cross-sectional and time-series analysis can be designed to reveal consumer behavior in terms of what people actually do in response to changes in water quality. The basic problem is the lack of data with which meaningful analyses can be made.

Although the theoretical literature is far ahead of the empirical work, the theory itself is plagued with ambiguities which only time and intellectual effort can unravel. Its evolution dates back only a few years and the implication for pollution control benefits is that something in excess of consumers' surplus of current users is ususally appropriate and legitimate. The extent of this "something" is the crucial issue.

In spite of this evolutionary condition, several vital dimensions of the problem are now being addressed in the literature:

- The role of risk-preference versus risk-aversion
- Policy outcomes as public goods (and the concomitant implications for direct questioning)
- Uncertainty as to future supply and/or demand
- Relevance of contingent claims markets as analogs
- Mixed-good. (private and social) conception of environmental goods.

Current empirical work is limited in its applicability for generalization, in that it focuses on high quality, unique environmental services, rather than medium or low quality services. This is not to dispute the future methodological value of such work, only to point out that the ratio of option value to (current) consumers' surplus may be quite different for Hells Canyon than for more mundane activities on the Delaware River.

One would hypothesize that the ratio of option value to consumers' surplus would be higher for the more unique sites, and that aggregation based on current empirical work would overstate total benefits. The rationale behind this hypothesis lies in the differential income elasticities for high and low-quality environment services. One would suspect the demand for high-quality services is more income-elastic than that for services of lower quality. Thus, the former will become relatively more valuable in the future, and consumers would be more likely to desire "insurance" of future supplies, should contingent claims markets exist. Individual investigators appear most likely to analyze unique, high-quality sites. In order to test the above hypothesis, one may need to promote similar research efforts for non-unique, lower-quality sites, rather than wait for decentralized researchers to ask this question.

Economists and administrators are in a rather obvious dilemma as to the extent to which option value estimates should be added to current user values. A market failure symptom is evident in the sense that contingent claims do not exist for environmental goods in the sense that they exist for some other goods. On the other hand, the current ability to estimate option values is admittedly weak, and may cast doubts on the validity of the more concrete estimates in other categories.

5. Property Values

The academician's traditional wisdom in benefit-cost analysis has been to exclude from consideration as efficiency benefits any increments in property values arising from public investment for which there is no corresponding increase in the output of goods or services. In other words, pecuniary externalities or simple income transfers have been netted out of the analysis. On the other hand, if there is in fact an increase in the output of goods or services, a more direct measure than property value increments is usually sought. For example, if crop damages were averted by flood control, both higher farm incomes and higher land values, due to higher farm incomes, would result. In this case, one would prefer to use the increase in net farm incomes as the measure of benefit.

Nevertheless, increments to property values do arise as a result of water quality improvement. This has been substantively documented by Dornbusch and Barrager (1973) and David and Lord (1969), although both the capability for generalization and the adequacy of their model specification must be questioned. David and Lord's measurement of water quality was much less precise than desired for purposes of extrapolation, and the Dornbusch and Barrager effort failed to measure water quality explicitly. These are inadequacies that can be rectified with further effort; the real question is the meaning, in the context of national efficiency, of even more adequately derived estimates. That is, what do increments in property values really reflect? The recent conclusion by Lind (1973) is that, in a general equilibrium model, most increments (or decreases) in land values can be ignored for benefit computation.

Property value increments may reflect an actualized option demand which should be included as an efficiency benefit. Pursuit of the relationships between water quality and property values should be viewed seriously from a strategic point of view, considering that existing behavioral damage functions for recreation and aesthetics are currently not capable of generalization to national levels.

The methodologies for estimating. both. recreation demands and option demands often rely on direct elicitation of responses, whereas property markets tend to reflect what people do, rather than what they say they will do. Since public access to water is increasingly difficult, property values may increasingly reflect an actualized option demand wherein buyers seek to assure, for private use, a continued supply of particular environmental services. To the extent that these option demands are satisfied, a service is produced by pollution control.

If sufficient relationships between water quality and property values were to become available, these might be used to derive generalized benefit estimates in terms of increments to property values. Caution would be needed to avoid "double-counting". On the other hand, those to whom property value increments would accrue are probably a small fraction of total active users.

More refined lines of questioning could be developed to explore option demand, including the degree to which people seek to secure greater certainty over resource services through property acquisition. To the extent that property acquisition does act as a hedge against uncertain future supplies, there is a "corresponding increase in the output of goods or services," and the criteria for benefit computation are not violated.

E. CONCLUSIONS AND RECOMMENDATIONS

This section lists the conclusions drawn from the foregone discussion and recommendations for future work.

The analytical base of welfare economics and U.S. EPA's data collection capability both provide hope for better benefit estimates, Although numerous other problems exist, the analytical foundations of welfare economics and the data collection capability of U.S. EPA both provide a basis on which to expect that improved benefit estimates can be obtained. As Tihansky (1975) points out in his detailed literature review, welfare economics provides a significant conceptual base which has not been rigorously adhered to in much of the empirical work. The theory for estimation of benefits is far more advanced than the empirical work; hence, welfare economics, *per se*, is not a limiting factor.

The estimates of national benefits, by category of benefit, now have vastly different precisions. Until these categories are made more nearly comparable, there is little capability for judging to what degree investment in water pollution control would be efficient. Estimates of *production* losses, including traditional waterborne disease, are reasonably firm, although they could be improved at a cost. However, estimates of *consumption* losses, including recreation, aesthetics, and survival dimensions of health, are much less firm.

The general prospects for improving the precision of estimates also differ greatly over the various categories. Additional analytical effort along conventional lines can resolve much of the variation in the production estimates. Also, technological change (biased toward production rather than consumption activities) may retard the rate at which these benefit streams grow over time. Increased precision in estimates of recreation benefits and option values will come slowly and probably fortuitously in the absence of a coordinated effort in benefit estimation.

Highest priority should be directed to generation of behavioral response functions which are more complete and useful than those few which now exist. Principal attention should be directed to generation of meaningful behavioral response functions with respect to water quality changes, which improves their capability for aggregation and provides a more general framework. It seems almost a hopeless strategy for U.S. EPA to continue retaining even the best consulting firms to periodically make efforts toward extrapolating existing studies, when the base studies themselves are not designed to be extrapolated.

Criteria need to be established to identify and fund high priority research on behavioral response functions. The ambitous nature of the current decision context, that of weighing aggregate national benefits against aggregate national costs, must be reconsidered; suboptimization in research design should become a pragmatic reality. Decision criteria then need to be set to identify and fund high-priority research settings in which to generate behavioral response functions to changes in water quality. A matrix relating types of pollutants to geographic regions should be identified, and priorities for future research established. The criteria which would be needed to set priorities, among different elements of the matrix, should include consideration of the current level of pollution control benefits, considering both mean values and differential precision of the estimates, the rate at which the benefit streams appears to be growing or declining, the likely cost (in money and time lag) of establishing the behavioral relationships.

The set of behavioral response functions should include services for which "option demands" might be exercised. Within the set of behavioral relationships to be identified are those which relate to willingness to pay to increase the certainty of future provision of selected consumption goods and services. The latter may include access to or availability of recreation activities or aesthetic uses where- water quality is a consideration and avoidance of waterborne health hazards (e.g., carcinogens and toxic chemicals).

A "reduction in travel cost" model offers potential for assessing recreation benefits at a level of aggregation higher than that which now exists. Empirical implementation of such a model will be more difficult than specification of theory. Crucial elements include identification of the entire set of water-based recreation activities within the preference set of the consumer and specification of subjective substitutability or complementarity between sites. Also, measurement of how water quality differences are related to these elements, ability to measure this relationship on a continuum, rather than for "clean" water and "polluted" water, and ability to test the equality of degradation versus restoration of water quality.

<u>A basic commitment should be made by EPA to establish a long-term "behavioral monitoring system" analogous to that established by the U.S. Geological Survey for assessing water quality</u>. The data sets for a carefully selected variety of sites would include measurement of basic economic and ecological data, objective and perceived water quality parameters, recreation activity, by type, intensity, and other characteristics, and property values, particularly for residential and recreational properties. The monitoring system would be longitudinal in that trends in both water quality and user behavior would be recorded, allowing for time-series analysis.

Selection of a variety of sites would also allow cross-sectional analysis. Periodic cross-sectional sampling could be done among recreationists and potential users. This sampling would not need to be done necessarily on a large-scale basis, but it would need to be done well. Samples of users could also be followed longitudinally; a substantial literature now exists on this methodology. Criteria would need to be established for selection of sites. Consideration should be given to selection of sites where significant changes (upward and downward) are occurring or are likely to occur in the water quality parameters and to selection of sites which differ significantly in socio-economic variables (so as to allow cross-sectional estimates of income elasticities).

The rationale behind the proposal to establish a monitoring system are:

- More adequate knowledge of behavioral responses with respect to price, income, and (perceived or objective) water quality changes need to be established before national benefits can be estimated

- Current inferential capacity of analyses based on direct questioning is largely unknown

- Changes in water quality are in fact occurring, and researchers should be taking advantage of this

- The conceptual and empirical dimensions of "option demand" are still evolving; the theoretical models ten years hence may well be more powerful than can be tested against the data unless steps are taken to accumulate a large set of data

- A monitoring system provides a continuing flow of information to decision makers and to their constituency; over time, behavioral relationships can be determined and made available, thus augmenting this flow of information as well as facilitating much more precise estimates of national benefits from pollution control.

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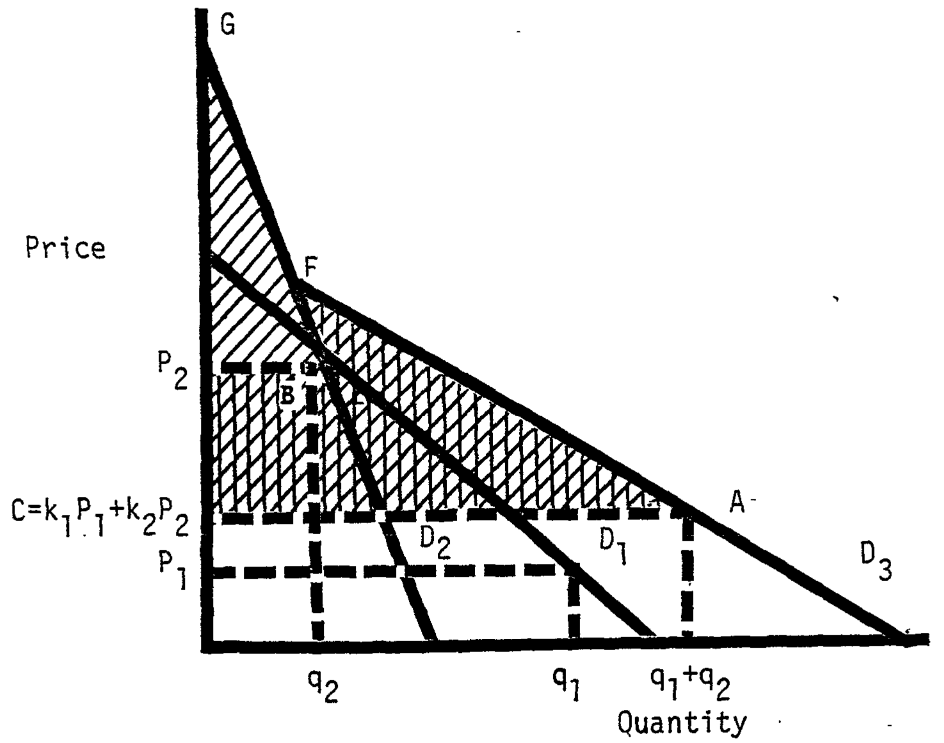
ATTACHMENT A. MODEL 1

Assume that a recreationist has separate demand functions (D_1 and D_2) for two non-priced sites which have, in his subjective judgment, some degree of substitutability. Assume also that these two sites constitute his "demand for outdoor recreation" (D_3). The demand function for each site is a function of both price (travel cost} variables and the quality parameter (Qu) of the site itself. Hence:

$$Q_1{}^d = f(P_1, Qu_1, P_2)$$

$$Q_2{}^d = f(P_2, Qu_2, P_1)$$

Diagrammatically:



Assume further that the relative price structures are such that the price of Site 1 (P_1) is low relative to the price of Site 2 (P_2), so that the quantity, q_1, exceeds q_2. Viewing the aggregate demand function, D_3, the the implicit "before pollution" price is $k_1p_1 + k_2p_2$, where the k_i's are weights determined by optimum quantities, q_1 and q_2. The total consumer's surplus which he derives is equal to CAFG.

Now assume that water quality at Site 1 deteriorates to the point that the recreationist no longer has any effective demand for this site. Such an event obviously reduces the utility of the consumer. When Site 1 disappears from the consumer's utility function, his equilibrium position changes from point A to point B. There is a reduction in his total quantity taken, an increase in the unit price paid (though not in the total bill), and a decrease in his utility. His consumer's surplus is now P_2BFG, and the double cross-hatched area ($CAFBP_2$) is his reduction in consumer's surplus due to pollution.

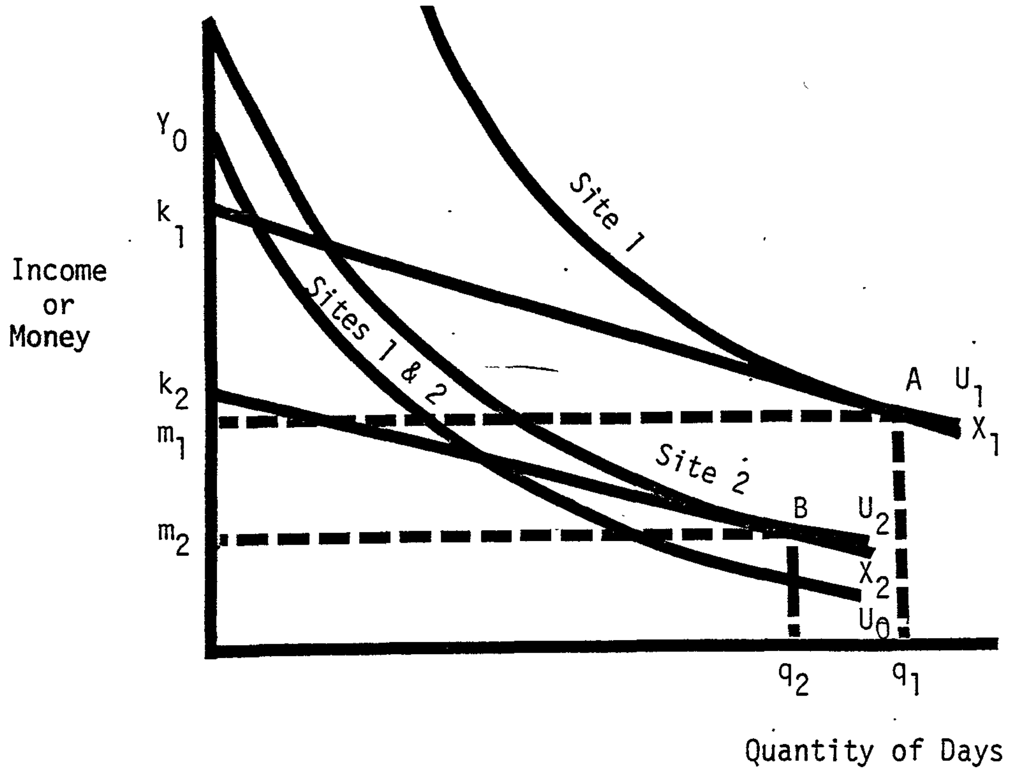
If the loss of Site 1 to pollution causes his demand for Site 2 to shift outward and become more inelastic (fewer substitutes), as might be expected, then the above decrease in willingness to pay has been overstated. Conversely, if the pollution of his "favorite" stream causes him to quit fishing, for example, altogether (due to inter-relatedness of sites and complementarity in terms of fixed factors such as tackle, etc.), then the reduction in willingness to pay is equal to CAFG, less the salvage value of his equipment.

ATTACHMENT B. MODEL 2

Consider that in a "no-pollution" situation, a recreationists's utility mapping for Site 1 or 2 contains indifference curve U_0 which passes through his current income position, Y_0. His willingness to substitute income to obtain additional units of recreation along U_0 is identical between sites 1 and 2. That is, the two sites are perfect substitutes for each other.

The cost of travel to the two sites, however, differs; Site 1 can be reached for a fixed outlay of (Y_0-k_1), which is essentially the cost of travel, lodging, and/or food required to reach and return from the site. Once the fixed costs of reaching the site are incurred, the variable costs (k_1X_1) per unit of time (e.g., on-site lodging and/or admission fees) become relevant in determining his optimum length of stay.

Site 2 is located farther from his home, thus the fixed costs of travel (Y_0-k_2) exceed those for Site 1. Assume, for simplicity, that the variable or on-site costs of the two sites are equal, or that (k_2X_2) is parallel to (k_1X_1).



In that the two sites are defined (initially) as perfect substitutes and their relative prices are unequal, a corner solution is reached. The recreationist will reach a higher (than U_0) indifference curve if he sacrifices (Y_0-m_1) income and consumes q_1 days at Site 1 (i.e., point A on indifference curve U_1).

Assume now that water quality at Site 1 deteriorates to the point where he is no longer willing to sacrifice- income to enjoy Site 1. Under the assumption that the demand for each site is a function of both site prices and its own quality dimension (i.e., U_2 retains the same curvature as U_0 and U_1, but is now relevant only for Site 2), the recreationist will now turn to Site 2, which can be reached only at higher travel costs. His optimum level of consumption is now q_2 days (all taken at Site 2) with a money outlay of (Y_0-m_2); i.e., point B on indifference curve U_2.

Note at this point that the model is probably of general relevance in that:

- Pollution leaves the consumer "worse-off" than before
- Pollution causes the distance traveled to increase
- Some recreation is still consumed, even though a site is "lost" to pollution
- The total money outlay for recreation increases as pollution and per-unit prices increase (i.e., the demand for outdoor recreation, in general, would seem to be inelastic, as with most broad categories of commodities)
- Variable or on-site costs probably do not differ greatly between non-polluted and previously non-polluted areas.

The model is simplistic, however, in that the two sites are initially defined as perfect substitutes, differ only in distance, and constitute his entire recreational demand. (The limiting nature of his assumption has important implications, to be discussed below.)

The "costs" of pollution, to the recreationist, can be defined as the reduction in willingness to pay which is incurred through pollution.

Similarly, the benefits to restoration of clean water (or prevention of damage) can be seen as the same quantity. Each is a mirror image of the other, ceteris paribus.[1] The Hicksian concept of "compensating variation" allows us to approximate the monetary value of this averted utility loss or potential utility gain. It asks: "How much would the consumer[2] have to be compensated to leave him as well off as before?" In this model, utility level U_1 could be regained by an outward shift in the price line from (k_2X_2) to (k_1X_1); i.e., an income transfer of the magnitude (k_1-k_2), or the difference in the fixed costs of travel, could leave the recreationist as well off as he was prior to pollution, given that on-site costs are the same in both cases.

This model illustrates two things. First, if the recreation sites are initially perfect substitutes, the relevant measurement of benefit is isolated in terms of additional travel costs alone. Any measures of benefits from quantity and quality changes are clearly duplicative, since they are already incorporated in the reasoning and diagram above. The model says this; if pollution causes a recreationist to incur $10 in additional travel cost to reach a more distant site, a $10 income transfer to him would theoretically leave him as well off as before, and hence, is a measurement of values foregone by pollution -- or benefits created by restoration. Second, the model identifies crucial needs for (a) extent to which pollution has caused substitutions between sites, and (b) data on additional per unit travel costs due to pollution. While these may or may not be available, the differences in total outlays (m_1-m_2) might be a suitable proxy.[3]

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[1]The critical limiting nature of this ceteris paribus assumption is examined on pages IV 21-22.

[2]The analysis is shown for those who participate in at least some recreation both with and without pollution. Other recreationists, however, would cease this type of consumption altogether with the demise of Site 1 (i.e., move to Y_0). In any empirical treatment, the willingness to pay of these (marginal) consumers would need to be added to that of existing (intramarginal) consumers.

[3] I would note, however, a difference in the ratios $\left(\frac{Y_0-m_1}{Y_0-m_2}\right)$, and $\left(\frac{Y_0-k_1}{Y_0-k_2}\right)$. If, for example, moving from B to A represents a 40 percent reduction in total costs $\left(\frac{Y_0-m_1}{Y_0-m_2} = 0.6\right)$, then this might involve (say) a 60 percent reduction in travel costs $\left(\frac{Y_0-k_1}{Y_0-k_2} = 0.4\right)$.

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15. SUPPLEMENTARY NOTES

Project Officer - Thomas E. Waddell

16. ABSTRACT

This provides a critical review of the current state-of-the-art and future prospects of estimating benefits of air and water pollution control. This report represents three independent critiques by three experts of benefit assessment methodologies. Specific aspects discussed include the nature and role of benefits, damage functions, valuation of effects, aggregation of results, and representation of uncertainties. The conceptual foundations of estimating pollution control benefits were presented and compared with empirical studies. It was concluded that while available estimates often do not adequately reflect the state-of-the-art, estimates of pollution control benefits would potentially be very useful to decision makers. The conceptual basis provided by economic theory for benefit estimation is adequate in most respects and far ahead of the corresponding empirical effort. A number of studies are guilty of failing to list explicitly critical assumptions or to express adequately uncertainty in the results while other studies have employed conceptual models that are inappropriate to the problem at hand or the available data. Damage functions underlying benefit estimates are frequently based on insufficient data and/or inadequate characterization of exposure and effects. National benefit estimates were found to be based on regional studies which are frequently inadequate in number and/or quality.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
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